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A dynamic bi-objective closed-loop supply chain network design considering supplier selection and remanufacturer subcontractors

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A B S T R A C T

This paper investigates the configuration of a closed-loop supply chain (CLSC) network, which involves suppliers, a single manufacturer, customers, collection/disassembly centers, disposal centers, a single recovery center and subcontractors. Due to the importance of green issues in the proposed supply chain, the efforts mainly focus on the suitable parts that form more durable and more sustainable products, reduce costs and help the environmental protection. To do so, an integrated framework is introduced which consists of a multi-attribute decision making (MADM) method and a multi-objective mathematical model that determines the material flow in the dynamic consecutive time segments of the network. This flow consists of parts and products which pass through the extant or potential facilities so that ultimately organize a CLSC network. Thereafter, a numerical example is examined by the augmented ε-constraint method and the results are demonstrated in a specific time horizon as an efficient solution. The results show the effects of time horizon in finding different solutions for each time segment. Furthermore, it shows how subcontractors can facilitate the flow of materials.

1. Introduction

Nowadays, most of the firms and organizations prefer to implement the principles of logistics management with the aim of getting goods with more appropriate price and quality. Some important purposes of logistics activities are production control, service processes, and customer needs identification. Indeed, the supply chain is a network of facilities that launch products or services to the market while it is responsible to supply the raw materials and convert them to the mid-products or final products. It also engages in distributing products to the customers. As a whole, a supply chain network may consist of suppliers, manufacturers, distributors, and customers. The topic of the traditional supply chain is about forward or direct flow of materials that mostly run from suppliers to manufacturers, manufacturers to distributors, and distributors to customers. However, in most industries, another important supply chain has been formed as reverse logistics where the materials flow in the reverse way. In other words, the products move from down-streams to the up-streams. As regards to the important role of the reverse logistics in the economic and environmental issues, it has been of great

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interest in recent years (Nazari, Rafiei, & Rabani, 2018). In order to provide more environmentally-friendly products besides taking back the used products at their end of life, some key concepts like government legislation, social responsibility, economic and environmental concerns, and customer awareness should be taken into account (Mutha & Pokharel, 2009). Over the past few years, the closed-loop supply chain management (CLSCM) has been appeared in the literature that indicates the integration of the forward channel as a traditional mode and the reverse channel as a modern one (Asl-Najafi et al., 2015; Sharma, 2012). Therefore, designing an efficient CLSC is one of the most basic requirements of an organization to gain more profit (Nukala & Gupta, 2007). On the other hand, manufacturers often outsource the corresponding processes and duties to provide sufficient confidence of regular delivering with acceptable quality and lead-time. Furthermore, it is obvious that an appropriate supplier selection plays a key role in each organization, because it reduces the costs and creates price competition. Indeed, choosing the most suitable supplier from a pool of available alternatives has now become extremely important and should be strongly taken into consideration (Karande & Chakraborty, 2013). In today's competitive business environment, quality, time, and price are three major factors that have significant effects on developing a new level of complexity in supplier selection. Although several investigations have been performed in the area of supplier selection in open loops, this is a novel subject in CLSC networks. There are some differences between supplier selection in open loop and closed-loop networks. Note that some criteria are more important in CLSCs than open loops. As a whole, several factors such as quality, delivery, capacity, and price are considered more in supplier selection. In closed-loops, product performance criteria would be more important than open loops because the products should have some specific features like strength, durability, and lightweight to be recoverable and reusable (Amin & Zhang, 2012).

In such a problem, criteria are in conflict with each other that result in more difficult situation for decision making. The problem can be separated into two interrelated subproblems. The first one determines that which suppliers should be selected and the second one indicates the amount of purchasing from each supplier. The flexibility of facilities and sites' capacities over the time horizon is another important point that has been deeply investigated in the current study. In this regard, we should consider future changes along with increasing knowledge about environmental friendly products to integrate economic and environmental factors. In this dynamic network design, all decisions are made over a time horizon which is finite and includes several time segments. Furthermore, it is essential to propose an approach that concentrates on other qualitative and quantitative criteria and reflects the manufacturer's policy in this field.

More importantly, as Fera et al. (2017) believe that strategic and tactical decisions are two major categories of supply chain management (SCM), we consider the both decisions in our study. The aim of this study is to find the optimal material flow, including products and parts along a CLSC with the aim of selecting appropriate suppliers. In other words, the general purpose of this paper is summarized as follows: selecting suppliers of new parts for the manufacturer, allocating orders to each supplier, determining the number of delivered products to the customers by the manufacturer, determining the number of returned products from the customers to the collection/disassembly centers, determining the amount of materials enter to the recovery or disposal centers, considering time horizon through the dynamic modeling, location of collection/disassembly centers, and optimizing the manufacturer's inventory of raw materials (or parts).

This problem will be modeled as a multi-objective programming problem that non-dominated solutions will be accepted as the best solutions for the model. The remainder of the paper is prepared as follows. In the next section, we show the relationship between our work and the previous literature. In Section 3, a bi-objective model is proposed for a dynamic closed-loop network design. The numerical results are presented in Section 4. We finally conclude the paper in Section 5.

2. Literature review

The most important task of the reverse channel is collecting and transporting the used products based on balancing between cost and environmental conditions. This function can be performed by a traditional forward chain, a separated reverse channel, or a combination of both. Design and optimization of a reverse logistics network include network structure, the number of layers, type of required facilities, and technologies. Many scholars prefer to apply the general principles to design a reverse logistics. However, some of the principles are strictly restricted by social factors and have not been qualified for the design process (Krikke et al., 2001). In a broader sense, the reverse logistics configuration should follow some specific economic and environmental perspectives such as the returned product ratio, product quality, greenness, etc. (Fleischmann et al., 2001).

Many of the papers in the area of reverse logistics network design in the related literature are based on case studies. In this regard, these models may not be general, because they have been designed for different conditions. Some authors have tried to suggest general models which can be implemented in a variety of industries. Moritz Fleischmann et al. (2001) introduced a general framework based on a location model for facilities with the focus on integrating the forward and reverse logistics. Salema et al. (2007) proposed a supply chain network design regarding constraints such as capacity, multi-product, and uncertainty on demand and return rate. Furthermore, Zhou et al. (2008) proposed a general model of restoring products in which repairing duration and remanufacturing products are investigated in depth. In this direction, Zhou et al. (2013) analyzed three important issues including environmental factors, governmental subsidies, and return ratio alongside the maximization of the aggregate profits in a green supply chain. Singh et al. (2014) presented an economic production model with time dependent demand in a reverse channel. Note that the main reason they implemented the reverse settings is the rework process. Saffar et al. (2015) investigated a bi-objective green supply chain problem under a fuzzy programming method to be able to face with uncertain conditions. They applied Jimenez approach (Jiménez, 1996) to change the problem to the crisp model and solved it using the ε-constraint method.

Supplier selection is one of the fundamental issues in the supply chain literature that can affect the performance of the channels. Supplier selection is a multi-criteria decision making because criteria and techniques are two essential elements in supplier selection (Thiruchelvam & Tookey, 2011). Ho et al. (2010) investigated 74 papers published between 2000 and 2008 and elicited the common criteria. The most used one was quality while the next criteria were delivery, price, cost, production capability, service, management, technology, financial parameters, flexibility, famousness, credibility, risk taking, safety, and external environment. Regarding this point that the criteria are in conflict with each other and improving one item makes the other one worse off, solving multi-criteria problems would find a complex nature. Thus, multi attribute decision making (MADM) methods are developed (Hwang & Yoon, 2012). For example, Yazdani (2014) discussed on the fact that how the right suppliers can be selected when fuzzy MADM process is available. In this regard, he implemented analytical hierarchy process (AHP) (Yazdani, 2014) method to find the weights of the criteria and then ranked them using fuzzy TOPSIS method.

In the MADM methods, the best alternative can be selected among with an available number of options while they also can set priority for all of the alternatives based on mathematical programming (Ozernoy, 1987). First, the mentioned methods examine the problem, specify the related attributes and assumptions, and then give an efficient solution for each problem (Ozernoy, 1992). Since the MADM methods and especially AHP are able to simultaneously investigate the both qualitative and quantitative criteria, a lot of attention has been paid to these methods over the past few years (Calabrese et al., 2013). Regarding these points, we apply the AHP method in our study. Table 1 illustrates the most important studies of recent years in the field of supply chain network design. With the aid of Table 1, we can discover the related literature gaps to present some efficient solutions and approaches.

Table 1
Findings of the previous literature

Authors	Objective function					Supply chain partners																							Direction	Product	Period	Parameters
	Cost/Profit	Defect Rates	Supplier's Risk	Supplier Weight/Quality	Delivery/Responsiveness	Suppliers	Manufacturer (Plants)	Production Centers	Warehouses	Remanufacturing Subcontractors	Wholesalers	Distributers	Retailer	Forward Facility Centers	Customers/1st Market (Default)	Customers/2nd Market	Collection Centers	Inspection Centers	Disassembly Centers	Recovery Centers	Redistributors	Remanufacturing Company	Second Customers	Refurbishing Centers	Disposal Centers	Incineration Centers	Recycling Centers	Inventory				
(Haleh & Hamidi, 2011)	P*		P	P		P	F																						FL	M	M	Fz
(Pishvaee et al., 2011)	P														F	F	P	P		P	P				F				CL	S	S	St
(Alumur et al., 2012)	P					F				P						F	F	P	P			P			F		F	P	RL	M	M	D
(Amin & Zhang, 2012)	P	P		P		P	F					F	F		F				P					P	F				CL	M	S	D
(Nenes & Nikolaidis, 2012)	P					P	F		F													F						P	CL	S	M	St
(Pishvaee & Razmi, 2012)	P							P							F		P							P		F	F		FL,RL	S	S	Fz
(Soleimani et al., 2013)	P					P	P		P			P	P		P	P	P		P		P				P			P	CL	M	M	D
(Amin & Zhang, 2013b)	P	P		P	P	P	F			P	F		F		F		F		F					P	F				CL	M	S	Fz
(Ramezani et al., 2013)	P			P	P	F	P					P		P		F	P								P				CL	M	S	St
(Amin & Zhang, 2013a)	P						P								P		P					P			F				CL	M	S	St
(Hatefi & Jolai, 2014)	P							P				P			F		P			P					P				CL	S	S	St
(Moghaddam, 2015)	P	P	P		P	P	P												F					P	F				CL	M	S	Fz
(Ghayebloo et al., 2015)	P					P	P								F				P								F		CL	M	S	D
This Paper	P			P		P	F			P					F		P		P	F					F			P	CL	M	M	D

* P: Potential, F: Fixed, FL: Forward logistics, M: Multi, Fz: Fuzzy, CL: Closed-loop, S: Single, St: Stochastic, RL: Reverse logistics, D: Deterministic.

3. Model formulation

In this section, we propose a comprehensive framework for supplier selection and supply chain network configuration that includes several steps. First, the top criteria for supplier selection are discovered and categorized. To do so, experts' opinions and experiences or previous studies can be useful. On the next step, these criteria will be reviewed and AHP gives a particular weight to each supplier based on each part. The obtained weight cooperating with another objective function and constraints will be put in a bi-objective mathematical programming to determine the material flow at each time horizon. That helps environmental protection through collecting and restoring the used items in a CLSC. The bi-objective mathematical model is solved using Augmented ε-Constraint (AUGMECON) (Mavrotas, 2009) and the efficient solutions are obtained.

As illustrated in Fig. 1, we assume a CLSC including a manufacturer, a recovery center, collection/disassembly centers, and disposal centers that launching products are done based on customers' demands. It is expected that under the adopted settings, some sold products may be returned to the supply chain. After collecting the returned products, the items which cannot be disassembled are transferred into the disposal centers. Other products will be disassembled and the usable parts will be sent to the recovery center to be tested and restored. In doing so, these parts are added to inventory and hold beside the fresh ones. Fresh parts are bought from external suppliers and the manufacturer produces final products by using parts. Since the collection/disassembly centers have limited capacities, we can reserve input parts to use in the next periods. In addition, the manufacturer has a limited capacity and may incur holding cost or use remanufacturing subcontractors. The manufacturer should make three major decisions: first, evaluating and selecting suppliers and allocating orders to them on different periods; second, determining the optimal number of parts and products in the supply chain flow on consecutive time segments; third, locating recovery and disposal facilities. Therefore, due to preventing sub-optimality on each mentioned steps, the manufacturer should integrate supplier selection and supply chain configuration.

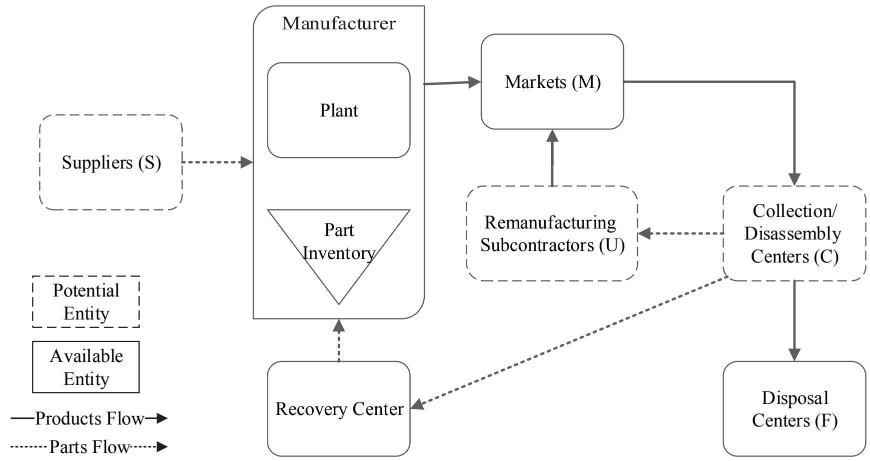

Fig. 1. Material flow in the proposed CLSC network

Here, we suggest a new framework for supplier selection which is useful in reverse logistics. The framework is categorized based on environment-related criteria (Amin & Zhang, 2012), organization-related and part-related criteria, called lean and agile criteria (Abdollahi et al., 2015).

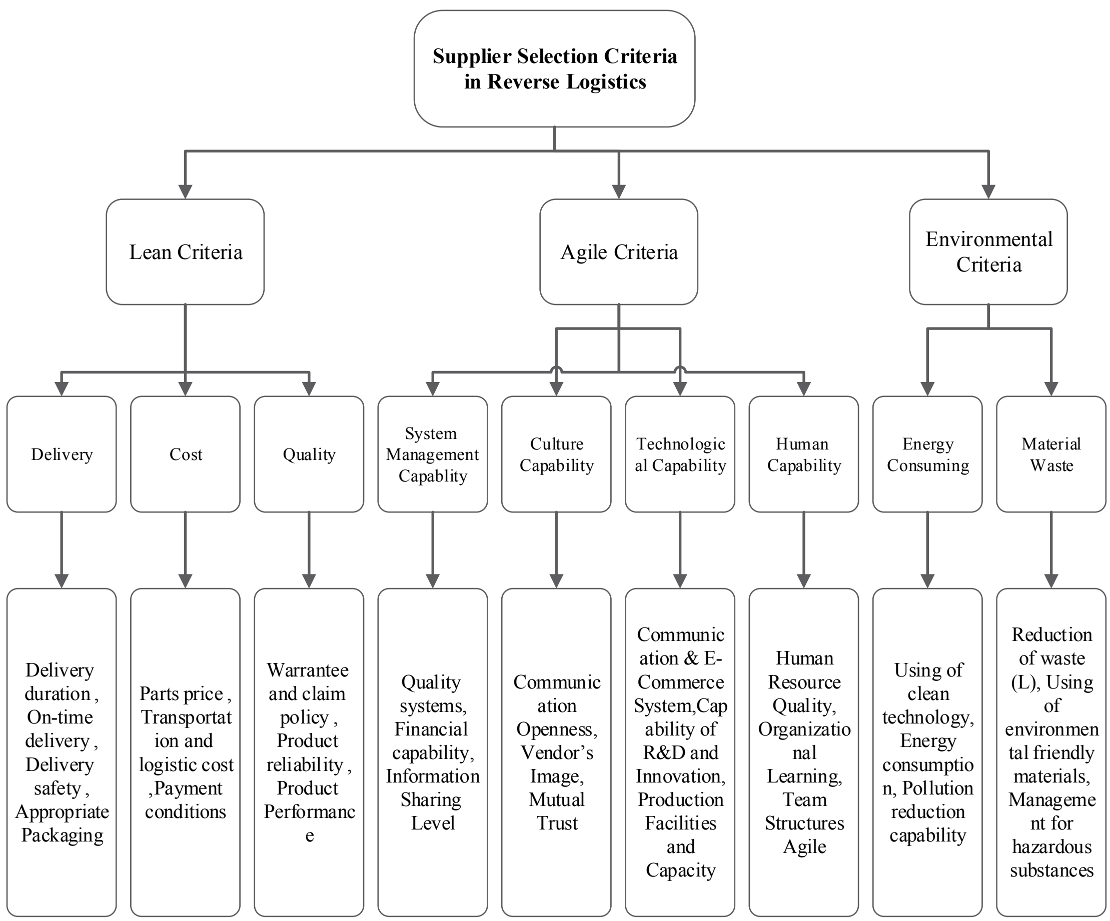

Fig. 2. Hierarchal structure for supplier selection

Fig. 2 illustrates the mentioned framework. Most studies have focused on supplier-related criteria such as delivery time, cost, financial capability, and experience without considering specific criteria relating to the processes and parts. In one of the first studies, Dickson (1966) designed a questionnaire and distributed it among 273 managers and procurement officers in North America. In doing so, he extracted 23 different criteria where the most important ones were quality, delivery, performance history, guarantee, claim policy, production capacity, net price, and other technical capabilities. In reverse logistics, other features like weight, durability, and strength should also be addressed. It should be noted that usable and recoverable parts can be utilized in the manufacturing process. In this process, not only parts and manufacturers should be entered, but also process-related parameters such as process capability and flexibility are essential. In addition, environment-related criteria play an important role. Pollution reduction and clean technology are some examples of green criteria in supplier selection. Interestingly, one of the reverse logistics objectives is the protection of the environment from damage. Hence, in the supplier selection process, significant weights should be considered to environment-related factors.

As a whole, AHP method has been most used for comparison between criteria and choosing the best alternatives. In the MADM techniques framework, AHP is one of the most used methods that has a decomposition approach so that breaks the complex problems into a structure with various objectives, criteria, and alternatives. In the first step, AHP calculates the relative importance of the variables with the aid of pairwise comparisons. Next, it selects the best option from among the all alternatives through the evaluation of the choices in the lowest stage. Indeed, the efficiency and effectiveness of the AHP method becomes more specific when the decision maker has a certain mindset. It is also noteworthy that AHP has a great potential to solve the problems that can be divided into some sub-criteria in a hierarchical path. Note that AHP can perform the prioritization mechanism by allocating a number obtained from a comparison to provide the relative importance of the criteria. Görener (2012) categorized the three basic principles of AHP method as: (1) model structure, (2) comparative judgment of the criteria and alternatives, and (3) synthesis of the priorities. To gain more details of all principles and steps of this method, we can find many studies in the literature like (Saaty, 1988).

Now, regarding Fig. 2, after comparing available suppliers by hierarchal structure, their global weights are obtained. To allocate purchasing amount from each supplier, the following mathematical model is applicable. This model is a bi-objective mathematical programming model that optimizes the defined variables. In the following, we introduce the sets, indices, decision variables, and parameters. In the next step, the mathematical model is explained in detail.

Sets	
$\boldsymbol{S}$	set of available suppliers
$\boldsymbol{U}$	set of remanufacturing subcontractors
$\boldsymbol{C}$	set of available places for collection/disassembly centers
$\boldsymbol{G}$	set of resources
$\boldsymbol{F}$	set of available places for disposal centers
$\boldsymbol{M}$	set of available markets
$\boldsymbol{R}$	manufacturer's recovery center
$\boldsymbol{L}$	manufacturer's plant
$\boldsymbol{P}$	set of products
$\boldsymbol{Q}$	set of parts
$\boldsymbol{T}$	set of time segments
Parameters	
PR^t_p	price of product $p \in P$ at period $t \in T$
CO^t_p	production cost of product $p \in P$ at period $t \in T$
CC^t_c	cost of establishing collection/disassembly center $c \in C$ at period $t \in T$
OC^t_{cp}	operation cost of product $p \in P$ (part $q \in Q$) in collection/disassembly center $c \in C$ (recovery center R) at period $t \in T$
TC^t_{ijp}	transfer cost of product $p \in P$ (part $q \in Q$) from site i to site j at period $t \in T$
SC^t_{uq}	selling price of disassembled part $q \in Q$ to subcontractor $u \in U$ at period $t \in T$

PS^t_{up}	purchasing price of recovered product $p \in P$ from subcontractor $u \in U$ at period $t \in T$
HC^t_q	holding cost of part $q \in Q$ at period $t \in T$
PC^t_{sq}	purchasing cost of part $q \in Q$ from supplier $s \in S$ at period $t \in T$
DE^t_{mp}	demand of market $m \in M$ for product $p \in P$ at period $t \in T$
WE_{sq}	weight of supplier $s \in S$ for part $q \in Q$ (which is obtained from the previous step)
NU_{pq}	number of part $q \in Q$ that used in product $p \in P$
RU_{cgp}	resource $g \in G$ used at collection/disassembly center $c \in C$ (recovery center R) by product $p \in P$ (part $q \in Q$)
RA^t_{cg}	volume of resource $g \in G$ available in collection/disassembly center $c \in C$ (recovery center R)
MC^t_p	manufacturer's capacity for product $p \in P$ at period $t \in T$
V_q	volume occupied by part $q \in Q$
IC^t	inventory capacity at period $t \in T$
λ^t_p	upper limit of waste rate for product $p \in P$ at period $t \in T$
CR^t_q	recovery center capacity for part $q \in Q$ at period $t \in T$
CS^t_{uq}	remanufacturing subcontractor capacity $u \in U$ for part $q \in Q$ at period $t \in T$
π_q	initial inventory for part $q \in Q$ at warehouse
Variables	
y^t_c	binary variable for establishing collection/disassembly center $c \in C$ at period $t \in T$
x^t_{ijp}	number of product $p \in P$ (part $q \in Q$) transferred from i to j at period $t \in T$
b^t_q	number of part $q \in Q$ holding in remanufacturer's inventory at period $t \in T$

Therefore, the model formulation is:

$$\begin{aligned}\max \quad Z_1 = &\sum_{t\in T}\sum_{m\in M}\sum_{p\in P}\left(PR^t_p - CO^t_p\right)x^t_{Lmp} - \sum_{t\in T}\sum_{s\in S}\sum_{q\in Q}PC^t_{sq}x^t_{sLq} - \sum_{t\in T}\sum_{m\in M}\sum_{p\in P}TC^t_{Lmp}x^t_{Lmp} \\ &-\sum_{t\in T}\sum_{m\in M}\sum_{c\in C}\sum_{p\in P}TC^t_{mcp}x^t_{mcp} - \sum_{t\in T}\sum_{c\in C}\sum_{f\in F}\sum_{p\in P}TC^t_{cfp}x^t_{cfp} - \sum_{t\in T}\sum_{c\in C}\sum_{u\in U}\sum_{q\in Q}TC^t_{cuq}x^t_{cuq} \\ &-\sum_{t\in T}\sum_{c\in C}\sum_{q\in Q}TC^t_{cRp}x^t_{cRp} - \sum_{t\in T}\sum_{u\in U}\sum_{m\in M}\sum_{p\in P}TC^t_{ump}x^t_{ump} - \sum_{t\in T}\sum_{q\in Q}TC^t_{RLq}x^t_{RLq} \\ &-\sum_{t\in T}\sum_{s\in S}\sum_{q\in Q}TC^t_{sLq}x^t_{sLq} - \sum_{t\in T}\sum_{m\in M}\sum_{c\in C}\sum_{p\in P}OC^t_{cp}x^t_{mcp} - \sum_{t\in T}\sum_{c\in C}\sum_{q\in Q}OC^t_{Rq}x^t_{cRq} \\ &-\sum_{t\in T}\sum_{m\in M}\sum_{u\in U}\sum_{p\in P}PS^t_{up}x^t_{ump} + \sum_{t\in T}\sum_{c\in C}\sum_{u\in U}\sum_{q\in Q}SC^t_{uq}x^t_{cuq} - \sum_{t\in T}\sum_{q\in Q}HC^t_q b^t_q \\ &-\sum_{t\in T}\sum_{c\in C}CC^t_c\left(y^t_c - y^{t-1}_c\right)\end{aligned} \tag{1}$$

$$\max \quad Z_2 = \sum_{t\in T}\sum_{s\in S}\sum_{q\in Q}WE_{sq}\times x^t_{sLq} \tag{2}$$

$$x^t_{Lmp} + \sum_{u\in U}x^t_{ump} \ge DE^t_{mp} \quad \forall t, m, p \tag{3}$$

$$y^t_c \times BM \ge \sum_{m\in M}x^t_{mcp} \quad \forall t, c, p \tag{4}$$

$$y^t_c \times BM \ge \sum_{f\in F}x^t_{cfp} \quad \forall t, c, p \tag{5}$$

$$y^{t-1}_c \le y^t_c \quad \forall t, c \tag{6}$$

$$b^t_q = b^{t-1}_q + x^t_{RLq} + \sum_{s\in S}x^t_{sLq} - \sum_{m\in M}\sum_{p\in P}NU_{pq}\times x^t_{Lmp} \quad \forall t, q \tag{7}$$

$$b^{-1}_q = \pi_q \tag{8}$$

$$\sum_{c\in C}\sum_{q\in Q}RU_{Rgq}\times x^t_{cRq} \le RA^t_{Rg} \quad \forall t, g \tag{9}$$

$$\sum_{m\in M}\sum_{p\in P} RU_{cgp}\times x_{mcp}^{t}\le RA_{cg}^{t}\ \forall t,c,g \tag{10}$$

$$\sum_{m\in M} x_{Lmp}^{t}\le MC_{p}^{t}\ \forall t,p \tag{11}$$

$$\sum_{q\in Q} V_{q} * b_{q}^{t}\le IC^{t}\ \forall t \tag{12}$$

$$\sum_{c\in C}\sum_{f\in F} x_{cfp}^{t}\le \lambda_{p}^{t}\ \forall t,p \tag{13}$$

$$x_{cuq}^{-1}=0\ \forall u,q,\mathrm{c} \tag{14}$$

$$x_{Lmp}^{t}+\sum_{u\in U} x_{ump}^{t}=\sum_{c\in C} x_{mcp}^{t}\ \forall t,p,m \tag{15}$$

$$\sum_{c\in C} x_{cuq}^{t-1}=\sum_{m\in M}\sum_{p\in P} NU_{pq}\times x_{ump}^{t}\ \ \forall u,q,t \tag{16}$$

$$\sum_{m\in M}\sum_{p\in P} NU_{pq}\times x_{mcp}^{t}=\sum_{u\in U} x_{cuq}^{t}+x_{cRq}^{t}+\sum_{f\in F}\sum_{p\in P} NU_{pq}\times x_{cfp}^{t}\ \ \forall q,t,c \tag{17}$$

$$\sum_{c\in C} x_{cRq}^{t}=x_{RLq}^{t}\ \ \forall q,t \tag{18}$$

$$x_{ijp}^{t}\ge 0\ \ \forall i,j,p,t \tag{19}$$

$$y_{c}^{t}\in\{0,1\}\ \forall c,t \tag{20}$$

$$b_{q}^{t}\ge 0\ \ \forall q,t \tag{21}$$

$$\sum_{c\in C} x_{cRq}^{t}+Sur_{Rq}^{t}=CR_{q}^{t}\ \ \forall q,t \tag{22}$$

$$\epsilon\times h_{q}^{t}\le Sur_{Rq}^{t}\le BM\times h_{q}^{t}\ \ \forall q,t \tag{23}$$

$$x_{cuq}^{t}\le BM\times\left(1-h_{q}^{t}\right)\ \forall c,u,q,t \tag{24}$$

$$\sum_{c\in C} x_{cuq}^{t}\le CS_{qu}^{t}\ \ \forall q,u,t \tag{25}$$

$$Sur_{Rq}^{t}\ge 0\ \forall q,t \tag{26}$$

$$h_{q}^{t}\in\{0,1\}\ \forall q,t \tag{27}$$

The first Objective function (1) maximizes the supply chain's profit. In the first term of this function, profit yielding from production that comes from the difference between the selling price and production cost is maximized. In the second term, the cost of purchasing parts from suppliers is minimized. In the next term, minimizing transportation cost is described. In the fourth term, operation cost of the recovery and collection/disassembly centers are minimized. In the next term, outsourcing cost of the remanufacturing subcontractors is minimized. The sixth term indicates the minimization of the holding cost. Finally, in the last term, the establishing costs of the collection/disassembly centers are minimized. The global weights which obtained through AHP in the previous step will be maximized on the second Objective function (2). Obviously, we are looking for purchasing from suppliers who gained larger weights. In each period, there is a demand from the market for each product. Constraints (3) indicate the demands of each market for each product. If one product is entered to a potential collection/disassembly center, that facility must be established. This will be done by parameter M which is considered in Constraints (4). On the other hand, if one product (one part) exits from a potential collection/disassembly center, that must be established. This will be done by parameter M which is considered in Constraints (5). According to Constraints (6), establishing cost of collection/disassembly centers are high and if we establish them, they will be usable on future periods. Number of inventory parts in each period are gained from the summation of four other terms shown in Eq. (7). The first term is the number of the remaining parts from the previous periods. The second term is the number of transported parts from the recovery center. The next term is the number of parts which are purchased

from suppliers. During the last term, decreased parts from inventory for the production process are considered. The plant has an initial inventory for each part shown in Eq. (8). Various resources are required to collect, disassemble, and recover parts and products. Furthermore, each of the resources is limited in facility sites. Eq. (9) and Eq. (10) prevent exceeding the limitation of the available resources. The manufacturer has a particular capacity for the production of each product. Eq. (11) considers an upper limit for the production process at each period. Each part occupies some spaces, which this has a constrained capacity and Eq. (12) regards that. One of the reverse logistics objectives is to help the environment by reducing waste production. If we consider a waste rate for each part at each period, we can limit transferred products to disposal centers. Eq. (13) explains this constraint. To integrate the proposed network, available facilities must have the same and rational input and output. Constraints (14)-(18) determine this rationality. According to Eq. (19), definitely, amount of the produced products are non-negative. If collection/disassembly center c be established at period t, the variable of Constraints (20) is one and it is zero otherwise. Based on Eq. (21), the number of inventory parts are non-negative. Constraints (22)-(27) are also taken into account, because we use the subcontractor as a recovery center capacity is completed. In these constraints, we considered $\boldsymbol{Sur}$ and $\boldsymbol{h}$ as auxiliary variables. On Constraints (22), the number of parts which are arrived to the recovery center must not exceed the capacity (if this equals to capacity, $\boldsymbol{Sur^t_{Rq}}$ will be zero and it will be positive, otherwise). If $\boldsymbol{Sur^t_{Rq}}$ equals to zero (completing recovery center capacity), variable $\boldsymbol{h^t_q}$ will be zero and if $\boldsymbol{Sur^t_{Rq}}$ be positive (not completing recovery center capacity), variable $\boldsymbol{h^t_q}$ will be one. According to the Eq. (24), if $\boldsymbol{h^t_q}$ equals to zero (completing recovery center capacity), then variable $\boldsymbol{x^t_{cuq}}$ will be zero.
To solve this bi-objective model, AUGMECON will be used. For the first time, this method is used by Mavrotas (2009) while it guarantees efficient solutions. The algorithm of the mentioned method has been implemented in Python programming using pulp module (Mitchell et al., 2011) and so the following results are obtained.

4. Numerical Example

In this section, we try to compare the suppliers' competency in each part. To do so, two suppliers are compared with each other in two separate parts. These comparisons have been done on a hierarchal structure. Explaining every comparison in different levels is out of this paper's scope and only final decision making weights for each part are explained in Appendix 1. For the beginning numerical review, the number of model sets should be specified. The manufacturer's plant is unique and it launches two kinds of products into two markets of customers. For manufacturing the product, two parts are utilized. In the first product, four first-parts and only one second-part are combined. Moreover, the second product is formed by two first-parts and five second-parts. In addition, as required, two potential collection/disassembly centers must be established. There are two disposal centers close to the collection/disassembly centers. If the capacity of the remanufacturing subcontractors becomes full, the manufacturer applies a recovery center. This model performs strategic decisions on five consecutive time segments. In the proposed model, a variety of parameters is effective. The most important one is the cost which is categorized into several items. The first category is transportation cost. The second one is operations cost. Input parts to plant, input products to disassembly centers and parts in recovery center are converted to appropriate output to be helpful for the following facility in the network. After selling unrecovered parts to the subcontractors, the recovered products must be bought from them. Thus, the third category of the cost is the purchase cost from remanufacturing subcontractors. Manufacturing inventory is the only place which material flow can stop there and it is a connector between discrete time instants. Maintaining of the parts in the inventory is costly and this is the fourth category. The fifth one is about establishing collection/disassembly centers. These small units take a large portion of cost. The sixth and the most important one is related to purchase from suppliers. One of the factors that pushes the manufacturers to collect the sold products is the high price of raw materials. On the other hand, financial items are not restricted to the costs. The manufacturer is able to consider benefit by selling products. Prices of manufactured products are described in Appendix 1. Note that after disassembling the collecting products, we can sell parts to subcontractors for recovery and remanufacturing that involve another portion of incomes. The amounts of all parameters are expressed in Appendix 1.

In addition, available resources in the recovery center ($\boldsymbol{RA^t_{Rg}}$) for both resources and for all time segments is 500 units, available resources in the collection/disassembly center ($\boldsymbol{RA^t_{cg}}$) for both resources, both centers and for all time segments are 5000 units, manufacturer capacity ($\boldsymbol{MC^t_p}$) for both products and for all time segments is 5000 units, inventory capacity ($\boldsymbol{IC^t}$) for all time segments is 900 units and upper limit of the waste rate ($\boldsymbol{\lambda^t_p}$) for both products and for all time segments is considered 60 units.

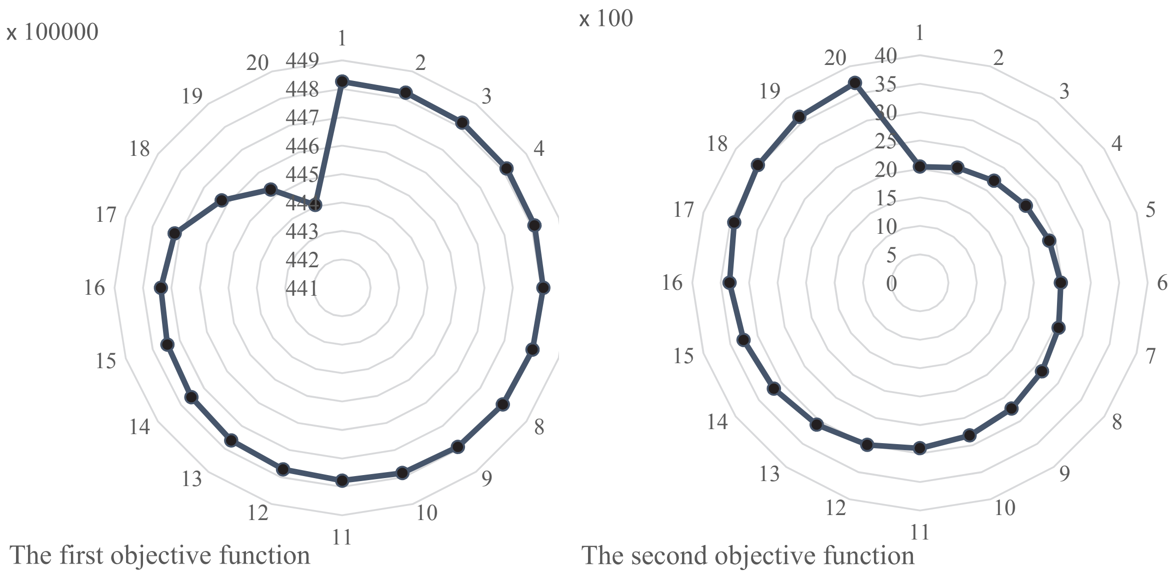

Fig. 3. Both objective functions for twenty efficient solutions

For generating 20 efficient solutions, this bi-objective model has been coded in Python programming language using augmented ε-constraint. The results of the material flow are illustrated in Appendix 2. Regarding the obtained efficient solutions, both objective functions change as depicted in Fig. 3. As can be seen in Fig. 3, achieving more utility in one of the objective functions makes the other one to get away from the best utility. Therefore, managers should do an appropriate trade-off between these two functions to obtain a favorable solution.

To analyze the impact of consecutive time segments on objective functions, we change them into less than five and solve the model for 20 efficient solutions. Fig. 4 illustrates the obtained results. As demonstrated in Fig. 4, the second objective function (right chart) is more sensitive to the time horizon changes than the first objective function (left chart). This means that the dependency of the profit on the number of decision making periods is not significant; however, supplier weights change linearly with a high slope as the periods increase. Therefore, when supplier selection problem is discussed in logistics, it is more reliable to utilize multi-period model than the single period ones.

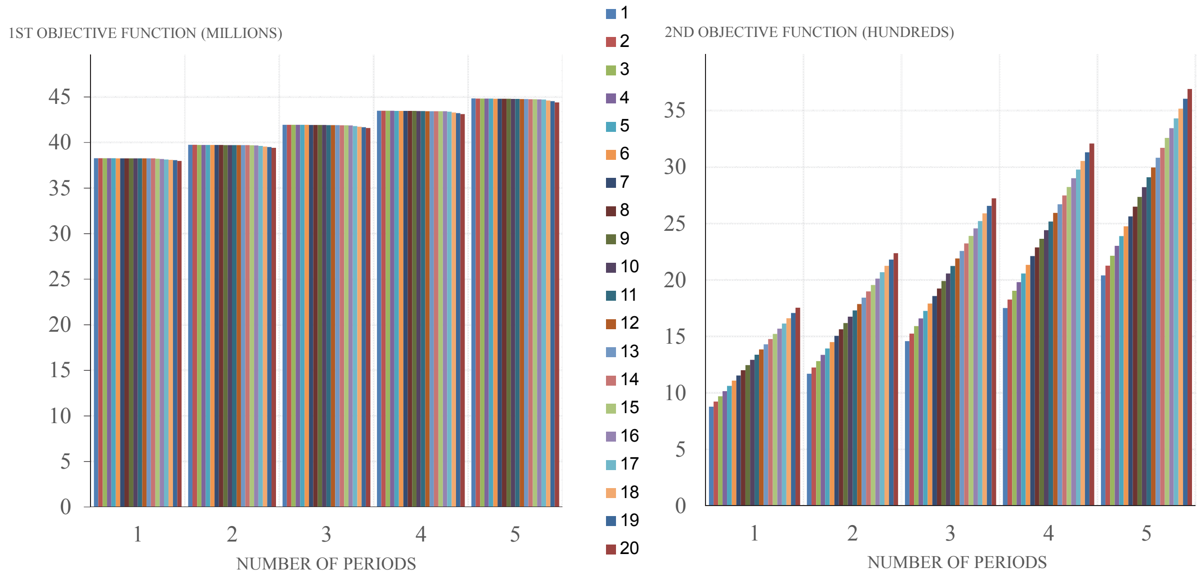

Fig.4. a. First objective functions vs. time horizon reduction

Fig.4. b. Second objective functions vs. time horizon reduction

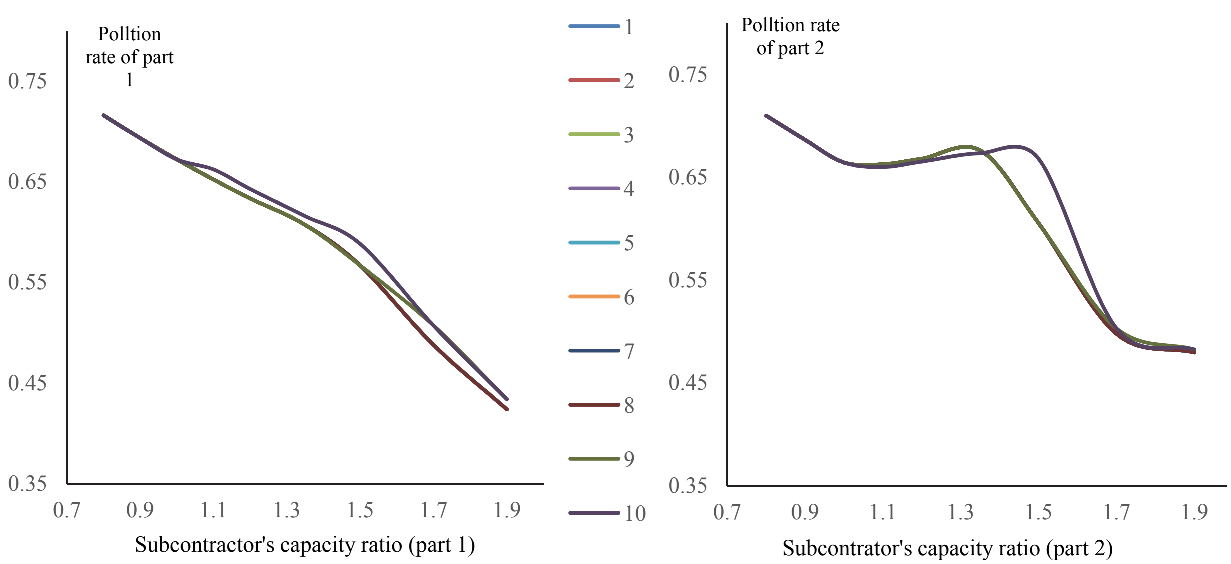

Fig. 5.a. Sensitivity of the pollution rate to the capacity of the remanufacturing subcontractors for part 1

Fig. 5.b. Sensitivity of the pollution rate to the capacity of the remanufacturing subcontractors for part 2

In another analyze, we tested the sensitivity of the green network to the capacity of the remanufacturing subcontractors. First, we denote the pollution rate of each part by $\boldsymbol{\eta_q}$ which can be defined as follows:

$$\eta_q = \frac{\sum_{c\in C}\sum_{f\in F}\sum_{p\in P}\sum_{t\in T} x^t_{cfp} NU_{pq}}{\sum_{c\in C}\sum_{u\in U}\sum_{t\in T} x^t_{cuq} + \sum_{c\in C}\sum_{t\in T} x^t_{cRq}} \tag{28}$$

Eq. (28) shows the ratio between parts transferred to disposal sites and the parts that are directly transferred to the manufacturer and the remanufacturers' site. Obviously, the larger η_q means the less greenness and more pollution to the environment. As can be seen in Fig. 5, we change the capacity of remanufacturing subcontractors to see the effect on the pollution rate (by implementing ten efficient solutions at each run). Although we have ten efficient solutions in Fig. 5, most of them are changing the same that each solution cannot be tracked distinctly. It is noteworthy that if the subcontractor's capacity becomes 1.5 times larger, the pollution rate of part 1 will become 0.57 in the ninth efficient solution. On the other hand, for the same solution, if the subcontractor's capacity becomes 1.5 times larger, the pollution rate of part 2 will become 0.61. As illustrated in Fig. 5, by increasing the capacity, the pollution rate decreases. Therefore, we can improve the greenness of the CLSC network by utilizing remanufacturing subcontractors that are more powerful.

5. Conclusion

During the last years, due to the increasing speed and volume of communications and competitive environment development in manufacturing and servicing organizations, the importance of designing and applying an economical supply chain has received managers' attentions significantly. As a whole, supply chain network design is planned based on effectiveness of strategic factors and considering customers' requirements. One of the important decisions in the supply chain is about strategic levels. The most important topic in supply chain strategic design is the network configuration and then appropriate supplier selection. This is performed in a particular time horizon, so it is a type of strategic decision making. One important benefit of implementing supplier selection is that the low-quality parts cannot be applied in the production process. More importantly, it leads to more sustainability in the network. On the other hand, decreasing in purchase and supply costs can help the manufacturers to be able to launch more high-quality products with lower price. In order to address this issue, an exact description of the problem, detecting gaps, and designing a mathematical model have been proposed in a bi-objective mathematical modeling framework. In the first step of this model, some information is required that is obtained through an MCDM method. At the next stage, AUGMECON method is introduced to find non-dominated solutions. Finally, we verified the model by a numerical example to examine the credibility of the model in right forecasting of the system's behavior. The proposed framework and its results have enough comprehensiveness for using in future studies about reverse logistics and CLSC because it paid much attention to all effective elements in the configuration. Therefore, the manufacturers in various industries can use this model and adjust or modify it. In Iran, public and private sectors such as Ministry of Industries and Business and Department of Environment are able to utilize the proposed model and improve a green supply chain. For future extensions, we suggest special case studies along developing the model. Furthermore, considering disruption risks can be helpful to make the model more practical.

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Appendix 1

Data (Mathematical model parameters)

PR^t_p

p/t	0	1	2	3	4
1	15000	15700	16400	17200	17900
2	16000	17000	18000	19000	20000

CO^t_p

p/t	0	1	2	3	4
1	3000	3200	3400	3600	3800
2	3800	4200	4600	5000	5400

$CC^t_c*0.001$

p/t	0	1	2	2	4
1	17240	17680	18570	19248	19913
2	17240	17680	18570	19248	19913

OC^t_{cp}

(c.p)/t	0	1	2	3	4
1.1	831	853	875	908	930
1.2	983	1013	1046	1072	1103
2.1	993	1020	1043	1078	1103
2.2	1032	1060	1095	1116	1141

TC^t_{Lmp}

(m.p)/t	0	1	2	3	4
1.1	40	42	45	48	50
1.2	45	49	53	57	61
2.1	49	51	57	60	64
2.2	54	58	63	67	71

TC^t_{mcp}

(m.c.p)/t	0	1	2	3	4
.11.1	62	67	70	74	78
1.21.	63	67	72	76	80
1.2.1	64	68	72	76	80
1.2.2	66	70	75	80	84
2.1.1	70	75	79	82	86
2.1.2	72	75	79	83	86
2.2.1	73	78	82	86	90
2.2.2	78	82	86	91	95

TC^t_{cfp}

(c.f.p)/t	0	1	2	3	4
.11.1	48	53	57	62	66
1.21.	50	54	59	63	67
1.2.1	52	57	61	64	68
1.2.2	53	57	60	63	66
2.1.1	54	58	63	66	70
2.1.2	59	62	67	72	76
2.2.1	50	53	57	62	65
2.2.2	51	54	57	62	65

TC^t_{cuq}

(c.u.q)/t	0	1	2	3	4
.11.1	13	15	17	19	21
1.21.	24	26	27	29	30
1.2.1	14	15	17	18	19
1.2.2	34	36	38	30	32
2.1.1	15	17	18	19	20
2.1.2	36	38	40	41	43
2.2.1	17	19	21	22	24
2.2.2	38	39	41	43	44

CS^t_{uq}

(u.q)/t	0	1	2	3	4
.11	511	518	524	531	538
1.2	447	452	259	465	471
2.1	258	264	270	277	282
2.2	372	378	385	392	398

CR^t_q

q/t	0	1	2	3	4
1	350	350	350	350	350
2	380	380	380	380	380

TC^t_{ump}

(u.m.p)/t	0	1	2	3	4
.11.1	13	15	17	19	34
1.21.	24	26	27	29	35
1.2.1	14	15	17	18	*37*
1.2.2	34	36	38	30	35
2.1.1	15	17	18	19	42
2.1.2	36	38	40	41	41
2.2.1	17	19	21	22	43
2.2.2	38	39	41	43	46

TC^t_{crq}

(c.q)/t	0	1	2	3	4
.11	21	24	26	28	30
1.2	24	26	28	30	32
2.1	25	27	29	30	32
2.2	26	27	29	32	33

TC^t_{RLq}

q/t	0	1	2	3	4
1	12	13	15	16	17
2	12	14	16	18	20

TC^t_{sLq}

(s.q)/t	0	1	2	3	4
.11	17	18	21	22	24
1.2	17	20	23	24	27
2.1	18	21	24	26	29
2.2	19	21	22	23	24

SC^t_{uq}

(u.q)/t	0	1	2	3	4
.11	450	470	500	530	555
1.2	550	580	620	640	675
2.1	500	530	570	590	625
2.2	580	6100	680	690	740

PS^t_{up}

(u.p)/t	0	1	2	3	4
.11	7500	7800	8200	8500	8850
1.2	8000	8500	9000	9500	10000
2.1	7900	8200	8600	9000	9350
2.2	8600	9000	9600	9900	10400

PC^t_{sq}

(s.q)/t	0	1	2	3	4
.11	500	520	540	560	580
1.2	600	630	650	680	705
2.1	540	570	600	620	650
2.2	620	660	700	720	760

DE^t_{mp}

(m.p)/t	0	1	2	3	4
.11	70	80	90	100	110
1.2	55	64	73	80	89
2.1	41	47	53	59	65
2.2	61	67	72	76	81

HC^t_q

q/t	0	1	2	3	4
1	25	29	33	38	42
2	28	34	40	47	53

NU_{pq}

p/q	1	2
1	4	1
2	2	5

WE_{sq}

s/q	1	2
1	0.54	0.24
2	0.46	0.76

RU_{cgp}

g/p	1	2
1	13	35
2	17	25

RU_{Rgq}

g/q	1	2
1	8	10
2	12	7

V_q

q	1	2
	1.8	2.6

Appendix 2

Results (Efficient solutions set for material flow variables)

$x^t_{sLq}{}^*$			Efficient solutions set																			
S	***q***	***t***	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1	0	614	614	614	614	614	614	614	614	614	614	614	614	614	614	614	614	614	614	614	614
1	1	1	454	454	454	454	454	454	454	454	454	454	454	454	454	454	454	454	454	454	454	454
1	1	2	452	452	452	452	452	452	452	452	452	452	452	452	452	452	452	452	452	452	452	452
1	1	3	446	446	446	446	446	446	446	446	446	446	446	446	446	446	446	446	446	446	446	446
1	1	4	634	634	634	634	634	634	634	634	634	634	634	634	634	634	634	634	634	634	634	1134
1	2	0	1022	855	688	521	354	187	20	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	1	105	105	105	105	105	105	105	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	2	446	446	446	446	446	446	446	446	446	446	334	167	0	0	0	0	0	0	0	0
1	2	3	431	431	431	431	431	431	431	389	222	55	0	0	0	0	0	0	0	0	0	0
1	2	4	650	650	650	650	650	650	650	650	650	650	650	650	650	483	316	149	0	0	0	0
2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	0	0	167	334	501	668	835	1002	1022	1022	1022	1022	1022	1022	1022	1022	1022	1022	1022	1022	1022
2	2	1	0	0	0	0	0	0	0	105	105	105	217	384	451	451	451	451	451	451	451	451
2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	100	100	100	100	100	100	100	100
2	2	3	0	0	0	0	0	0	0	42	209	376	431	431	431	431	431	431	431	431	431	431
2	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	167	334	501	662	777	891	650

$x^t_{Lmp}{}^*$			Efficient solutions set																			
m	***p***	***t***	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1	0	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
1	1	1	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80
1	1	2	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88
1	1	3	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88
1	1	4	115	115	115	115	115	115	115	115	115	115	115	115	115	115	115	115	115	115	115	115
2	1	0	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41
2	1	1	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
2	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	0	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55
1	2	1	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64	64
1	2	2	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72
1	2	3	69	69	69	69	69	69	69	69	69	69	69	69	69	69	69	69	69	69	69	69
1	2	4	107	107	107	107	107	107	107	107	107	107	107	107	107	107	107	107	107	107	107	107
2	2	0	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61
2	2	1	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

			$x^t_{mcp}{}^*$	Efficient solutions set																			
m	***c***	***p***	***t***	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1	1	0	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70
1	1	1	1	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80
1	1	1	2	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
1	1	1	3	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
1	1	1	4	137	137	137	137	137	137	137	137	137	137	137	137	137	137	137	137	137	137	137	137
1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	1	4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	0	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41
2	1	1	1	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
2	1	1	2	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53
2	1	1	3	59	59	59	59	59	59	59	59	59	59	59	59	59	59	59	59	59	59	59	59
2	1	1	4	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65
2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	2	0	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41
1	1	2	1	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29
1	1	2	2	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18
1	1	2	3	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
1	1	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	2	0	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
1	2	2	1	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
1	2	2	2	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55
1	2	2	3	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72
1	2	2	4	124	124	124	124	124	124	124	124	124	124	124	124	124	124	124	124	124	124	124	124
2	1	2	0	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61	61
2	1	2	1	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67	67
2	1	2	2	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72
2	1	2	3	76	76	76	76	76	76	76	76	76	76	76	76	76	76	76	76	76	76	76	76
2	1	2	4	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63	63
2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	2	4	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19	19

$x^{t}_{cfp}{}^{*}$				Efficient solutions set																			
c	***f***	***p***	***t***	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1	1	0	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
1	1	1	1	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
1	1	1	2	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
1	1	1	3	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54
1	1	1	4	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18
1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	1	3	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
2	2	1	4	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42
1	1	2	0	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46
1	1	2	1	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
1	1	2	2	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
1	1	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	2	0	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
2	2	2	1	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
2	2	2	2	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55
2	2	2	3	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
2	2	2	4	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60

$x^{t}_{cuq}{}^{*}$				Efficient solutions set																			
c	***u***	***q***	***t***	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1	1	0	274	274	274	274	274	274	274	274	274	274	274	274	274	274	274	274	274	274	274	274
1	1	1	1	368	368	368	368	368	368	368	368	368	368	368	368	368	368	368	368	368	368	368	368
1	1	1	2	441	441	441	441	441	441	441	441	441	441	441	441	441	441	441	441	441	441	441	441
1	1	1	3	501	501	501	501	501	501	501	501	501	501	501	501	501	501	501	501	501	501	501	501
1	1	1	4	538	538	538	538	538	538	538	538	538	538	538	538	538	538	538	538	538	538	538	538
1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	1	2	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
1	2	1	3	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46	46
1	2	1	4	282	282	282	282	282	282	282	282	282	282	282	282	282	282	282	282	282	282	282	282
2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	2	0	331	331	331	331	331	331	331	331	331	331	331	331	331	331	331	331	331	331	331	331
1	1	2	1	422	422	422	422	422	422	422	422	422	422	422	422	422	422	422	422	422	422	422	422
1	1	2	2	459	459	459	459	459	459	459	459	459	459	459	459	459	459	459	459	459	459	459	459
1	1	2	3	410	410	410	410	410	410	410	410	410	410	410	410	410	410	410	410	410	410	410	410
1	1	2	4	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	2	2	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49	49
1	2	2	3	114	114	114	114	114	114	114	114	114	114	114	114	114	114	114	114	114	114	114	114
1	2	2	4	398	398	398	398	398	398	398	398	398	398	398	398	398	398	398	398	398	398	398	398
2	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	2	3	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55	55
2	1	2	4	371	371	371	371	371	371	371	371	371	371	371	371	371	371	371	371	371	371	371	371
2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

$x^t_{ump}{}^*$				Efficient solutions set																			
u	***m***	***p***	***t***	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
1	1	1	3	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
1	1	1	4	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22
2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	1	1	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39	39
1	2	1	2	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53	53
1	2	1	3	59	59	59	59	59	59	59	59	59	59	59	59	59	59	59	59	59	59	59	59
1	2	1	4	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65
2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	2	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
1	1	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	2	3	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
2	1	2	4	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17
1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	2	1	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58	58
1	2	2	2	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72	72
1	2	2	3	76	76	76	76	76	76	76	76	76	76	76	76	76	76	76	76	76	76	76	76
1	2	2	4	76	76	76	76	76	76	76	76	76	76	76	76	76	76	76	76	76	76	76	76
2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	2	4	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6

$x^t_{cRq}{}^*$			Efficient solutions set																			
c	***q***	***t***	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1	0	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42
1	1	1	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42
1	1	2	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42
1	1	3	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42
1	1	4	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42
2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

x^t_{RLq}		Efficient solutions set																			
q	***t***	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42
1	1	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42
1	2	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42
1	3	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42
1	4	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0