Characterization of soft sets as soft semigroups

Abstract. In the literature, various algebraic structures of soft sets and their applications in decision making problems had been given. However some semigroup properties associated with soft sets have not been exhausted. This paper characterizes soft sets as an abstract structure of semigroups and presents some semigroup properties associated with soft sets.

Keywords: Soft sets, soft semigroups, soft morphisms, soft regular semigroups.

Mathematics Subject Classification: 20M10

1. Introduction

It is known that mathematical models have been extensively used in real world problems which are related to engineering, computer sciences economics, social, natural and medical sciences e.tc. Because of various uncertainties arising in real world situations, methods of classical mathematics may not be successfully applied to solve them. Zadeh [19] coined his remarkable theory of fuzzy sets which has to do with a kind of uncertainty referred to as "fuzziness" and which is due to partial membership of an element in a set. Although fuzzy set is very successful in handling uncertainties and partial belongingness of an element in a set, it cannot model all sorts of uncertainties prevailing in different real physical problems. Thus, search for new theories emerged. To overcome these peculiarities, Molodtsov [10] then initiated a novel concept of soft set they which is completely a different approach for modeling uncertainty. This uses parameterization as its main tool to handle uncertainty associated with real world problems.

The distinguishing attribute of soft set theory is that unlike probability theory and fuzzy set theory, it does not uphold a precise quantity. Molodtsov successfully applied the soft set theory into several directions such as smoothness of functions, game theory and so on. A soft set is a classification of elements with respect to some given set of parameters. It has been shown that soft set is more general in nature and has more capability in handling uncertain information. It is important to note that a fuzzy set or a rough set is considered as a special case of soft sets. In past few years, the fundamental theory of soft set has been studied by various researchers. Research involving soft sets and their application in various fields of science and Technology is currently going on.

Maji and Roy [8] first gave a practical application of soft sets in decision making problems and defined soft binary operations like AND, OR, UNION, INTERSECTION of two sets.

Apart from the rich application of soft set theory, its algebraic structures have also been studied extensively by some researchers. These include the work of Aktas and Cagman [1] in soft groups and their basic properties, Feng et al [6] who introduced the notion of soft semirings, Acar et al [3] discussed the concept of soft rings and soft ideals of soft rings, Jayanta [7] gave the algebraic structure of soft sets and Muhammad et al [11] who have a new approach to study these structures.

Also, some researchers like Maji et al [8], Alkhazaleh et al [4], Pinak [12], Singh et al [15] have combined soft sets with other sets such as fuzzy set, rough set, multi set to generate structures like fuzzy soft sets, rough soft, mult-soft sets among others.

Applications of these aforementioned structures in decision making, medical diagnosis, forecasting etc have been studied by some researchers like Roy and Maji [13], Das and Borgohaim [5], Rajarajeswan and Dhame lak Shimi [14], Sai [16], Udhaya et al [17] and so on.

In the literature, some researchers had given various algebraic structures of soft sets and their application in decision making problems. However to the best of our knowledge, some semigroup properties associated with soft set have not been exhausted. Therefore this work characterizes soft sets as an abstract structure of semigroups and presents some semigroup properties associated with soft sets.

2. Preliminaries

In this section, we recall some definitions as well as some known results which will be useful in this paper. For notation and terminologies not mentioned in this paper, the reader is referred to [2], [7], [8], [9] and [18].

Definition 2.1 [10]. Let U be given universe and E a set of parameter that describes elements of U. Let A be a subset of E and $P(U)$ denote the family of all subsets of U. i.e $P(U)$ denote the power set of U. The soft set of A is the pair (F, A) where F is a mapping given by $F : A \to P(U)$.

A soft set (F, A) can be seen as a parameterized family of subset of the set U. For each $e \epsilon A$, the set $F(e) \epsilon U$ is called e – approximate element of the set (F, A). It is important to note that other notations for soft sets are F_A or (F_A, E) and so on.

In this work, we shall use these notations interchangeably.

Example 2.2. Suppose a universe U is the set of six cars in a gallery given by $U = \{c_1, c_2, c_3, c_4, c_5, c_6\}$ and $A = \{e_1, e_2, e_3, e_4\} \subseteq E$ is the set of some key parameters that stand out from the cars in the gallery where $e_i = \{i = 1,2,3,4\}$ stand for "Technological", "Fast", "Cheap" and "Safety" respectively. Anyone who comes to the gallery can construct a soft set (F_A, E) to express of the properties of the vehicles that express the parameters they want.

Now suppose a person's choices are: $F_A(e_1) = \{c_2, c_4, c_5, c_6\}, F_A(e_2) = \{c_1, c_2, c_3, c_4, c_5\}$, $F_A(e_3) = \{c_1, c_3, c_4, c_6\}$ and $F_A(e_4) = \{c_1, c_2, c_4, c_5, c_6\}$. Then the soft set (F_A, E) is the parameterized family $\{F_A(e_i), i = 1,2,3,4\}$ of subset of U given by

$$F_A = \begin{cases} (e_1, \{c_2, c_4, c_5, c_6\}),\ (e_2, \{c_1, c_2, c_3, c_4, c_5\}) \\ (e_3, \{c_1, c_3, c_4, c_6\}),\ (e_4, \{c_1, c_2, c_4, c_5, c_6\}) \end{cases}$$

where for example $F_A(e_3)$ means cars (cheap), whose functional value, called the e_3 -approximate value set, is the set $\{c_1, c_3, c_4, c_6\}$. Thus, we can view the soft set (F_A, E) as consisting of a collection of approximations which has two parts namely;

i) A predicate $F_A(e_1)$ or $F_A(e_2)$ or $F_A(e_3)$ or $F_A(e_4)$ and

ii) The approximate set $\{c_2, c_4, c_5, c_6\}$, $\{c_1, c_2, c_3, c_4, c_5\}$, $\{c_1, c_3, c_4, c_6\}$, $\{c_1, c_2, c_4, c_5, c_6\}$

Definition 2.3. A soft set (F_A, E) over U is said to be a null soft set over U if $F_A(e) = \emptyset$ for all $e \epsilon A$.

Definition 2.4. Let $(F, A)$and (G, B) be two soft sets over common universe U, we say that (F, A) is a soft set of (G, B) if $A \sqsubseteq B$ and for all $e \epsilon$, $F_A(e) = G_B(e)$.

Definition 2.5. [9] . Let $(F, A)$and (G, B) be two soft sets then their union over a common universe U is denoted by $(F, A)\ \breve{\cup}\ (G, B) = (H, C)$ where $C = A \cup B$ and for all $c \epsilon C, (H, C)$ is defined by

$$H(e) = \begin{cases} F(e) & \text{if } c \in A - B \\ G(e) & \text{if } c \in B - A \\ F(e) \cup G(e) & \text{if } c \in A \cap B \end{cases}$$

Definition 2.6 [2] Let $(F, A)$and (G, B) be two soft sets over common universe U. Then the restricted union of two soft sets denoted by $(F, A) \cup_R (G, B)$ is the soft set (H, C), where $C = A \cap B$ and for all $c \in C$, $H(e) = F(e) \cup G(e)$. The restricted intersection is defined similarly.

Definition 2.7 [9]. Let $(F, A)$and (G, B) be two soft sets over common universe U. Then we have that

i. $(F, A) \wedge (G, B)$ is a soft set defined by $(F, A) \wedge (G, B) = (H, A \times B)$, where $H(\alpha, \beta) = F(\alpha) \cap G(\beta)$ for all $(\alpha, \beta) \in A \times B$, where $\cap$ is the intersection operation of sets.

ii. $(F, A) \vee (G, B)$ is a soft set defined by $(F, A) \vee (G, B) = (K, A \times B)$, where $K(\alpha, \beta) = F(\alpha) \cup G(\beta)$ for all $(\alpha, \beta) \in A \times B$, where $\cup$ is the union operation of sets.

The following Proposition give some result are obtained in [9]

Proposition 2.8 [9]. Let (F, A) and (G, B) be two soft sets over common universe U. Then

i. $\left((F, A) \cup (G, B)\right)^c = (F, A)^c \cup (G, B)^C$

ii. $\left((F, A) \cap (G, B)\right)^c = (F, A)^c \cap (G, B)^C$

Definition 2.9. [18]. The extended intersection of two soft set (F, A) and (G, B) be two soft sets over common universe U is the soft set (H, C) where $C = A \cup B$ and for all $c \in C$, we have that

$$H(c) = \begin{cases} F(c) & \text{if } c \in A - B \\ G(c) & \text{if } c \in B - A \\ F(c) \cup G(c) & \text{if } c \in A \cap B \end{cases}$$

We write $(F, A) \cap_\epsilon (G, B) = (H, C)$. The extended union is defined similarly.

It is important to note that the De Morgan's law also holds for the extended intersection and union.

Theorem 2.10. [18]. Let (F, A) and (G, B) be two soft sets over common universe U. Then we have the following;

i. $\left((F, A) \cup_\epsilon (G, B)\right)^c = (F, A)^c \cap_\epsilon (G, B)^C$

ii. $\left((F, A) \cap_\epsilon (G, B)\right)^c = (F, A)^c \cup_\epsilon (G, B)^C$

Lemma 2.11. [18]. Let $(F,A),(G,B)$ and (H,C) be two soft sets over common universe U. Then we have the following statement hold.

$$\big((F,A)\cap_R (G,B)\big)\cup_\epsilon\ (H,C)=\big((F,A)\cup_\epsilon (H,C)\big)\cap_R\big((G,B)\cup_\epsilon (H,C)\big)$$

where $A\cap B\neq\emptyset$.

3. Main Results

In this section, we characterize some soft sets as soft semigroups and present some semigroup properties associated with the hybrid algebraic structure.

Let S be a semigroup and let $E=\{e_1,e_2,\dots,e_n\}$ be a set of parameters with $A\subseteq E$. Let $f:A\rightarrow P(S)$ be a mapping where $P(S)$ is the power set of S. Then a non empty soft set (F,A) over S is called a soft semigroup if and only if for each $a\ \epsilon\ A, f(a)$ is a subsemigroup of S, i.e $x,y\ \epsilon\ f(a)\Longrightarrow xy\ \epsilon\ f(a)$.

Let S be a semigroup and let E be a set of parameters with $A\subseteq E$. Let $f:A\rightarrow P(S)$ be a mapping where $P(S)$ is the power set of S. Then (F,A) is a soft ideal over S if and only if for each $a\ \epsilon\ A, f(a)$ is an ideal of S, i.e $x\ \epsilon\ f(a),\ r\ \epsilon\ S\Longrightarrow rx\ \epsilon\ f(a)$ and $xr\ \epsilon\ f(a)$.

Example 3.1. Consider $S=\{a,b,c,d\}$ be a semigroup defined by the Cayley's table below

$\star$	a	b	c	d
a	a	a	a	a
b	a	a	a	a
c	a	a	b	a
d	a	a	b	b

Consider the soft set (F,S) where $F:S\rightarrow P(S)$ is defined as $F(a)=\{a\}$, $F(b)=\{a,b\}$, $F(c)=\{a,b,c\}$, $F(d)=\{a,b,d\}$. It is clear that (F,S) is a soft semigroup over S since $F(x)$ is a subsemigroup of S for all $x\ \epsilon\ S$.

It is important to note that not every soft set over a semigroup S, is a soft semigroup over S. For instance, if we now consider the soft set (G,S) in which $G:S\rightarrow P(S)$ is defined as $G(b)=\{b\}$, then obviously (G,S) is not a soft semigroup over S since $G(b)=\{b\}$ is not a subsemigroup of S.

The following results give some properties of soft semigroups

Lemma 3.2. Let (F, A) and (G, B) be two soft semigroups over a semigroup S. Then the restricted intersection $(F, A) \cap_R (G, B)$ is also a soft semigroup provided that is non empty.

Proof. We have known that $(F, A) \cap_R (G, B) = (H, C)$ where $C = A \cap B \neq \emptyset$ and $H(c) = F(c) \cap G(c)$ for all $c \epsilon C$. Obviously, it is either empty or a subsemigroup of S. Thus, (H, C) is a soft semigroup over S.

Lemma 3.3. Suppose (F, A) and (G, B) be two soft semigroups over a semigroup S such that $A \cap B \neq \emptyset$. Then the extended union $(F, A) \cup_\epsilon (G, B)$ is also a soft semigroup over S.

Proof. We know that $(F, A) \cup_\epsilon (G, B) = (H, C)$ and $A \cap B \neq \emptyset$, for all $c \epsilon C = A \cup B$ either $c \epsilon A - B$ or $c \epsilon B - A$. Now if $c \epsilon A - B$ then $H(c) = F(c)$, and if $c \epsilon B - A$ then $H(c) = G(c)$. But in both cases, $H(c)$ is a subsemigroup of S. Hence, (H, C) is a soft semigroup of S.

Lemma 3.4. Suppose (F, A) and (G, B) be two soft ideals over S. Then the restricted intersection $(F, A) \cap_R (G, B)$ is also a soft ideal over S, which is contained in (F, A) and (G, B) for $(F, A) \cap_R (G, B) = \emptyset$.

Proof. Obviously, $(F, A) \cap_R (G, B) = (H, C)$ where $C = A \cap B \neq \emptyset$ and $H(c) = F(c) \cap G(c)$, is either empty or an ideal of S. Thus (H, C) is a soft ideal over S.
It can be easily seen that $A \cap B \subseteq A$ and $A \cap B \subseteq B$. Moreso, $H(c) \subseteq F(c)$ and $H(c) \subseteq G(c)$ so that $(H, C) \subseteq (F, A)$ and $(H, C) \subseteq (G, B)$.

The lemma above is also applicable for the extended union as shown below

Lemma 3.5. Let (F, A) and (G, B) be two soft ideals over S. Then the extended union $(F, A) \cup_\epsilon (G, B)$ is also a soft ideal over S containing (F, A) and (G, B).

Proof. Since $(F, A) \cup_\epsilon (G, B) = (H, C)$, so for all $c \epsilon C = A \cup B$ either $c \epsilon A - B$ or $c \epsilon B - A$. If $c \epsilon A - B$ then $H(c) = F(c)$, if $c \epsilon B - A$ then $H(c) = G(c)$ and if $c \epsilon A \cap B$ then $H(c) = F(c) \cup G(c)$, in all cases, $H(c)$ is an ideal of S.
Consequently, (H, C) is a soft ideal over S.
Obviously, $(F, A) \subseteq (H, C)$ and $(G, B) \subseteq (H, C)$.

The theorem below shows that if we let the parameter A to be fixed, then the distributive law holds for soft ideals over S.

Theorem 3.6. Let (F,A), (G,B) and (H,A) be two soft ideals over S. Then the following statement holds.

$$\big((F,A) \cup_R (G,A)\big) \cap_R (H,A) = \big((F,A) \cap_R (H,A)\big) \cup_R \big((G,A) \cap_R (H,A)\big)$$

Proof. From the LHS, we have that

$$\big((F,A) \cup_R (G,A)\big) \cap_R (H,A) = (M,A) \cap_R (H,A)$$

where $(F,A) \cup_R (G,A) = (M,A)$ and $M(a) = F(a) \cup G(a)$.

So that $(M,A) \cap_R (H,A) = (N,A)$ and

$$\begin{aligned} N(a) &= M(a) \cap H(a) \\ &= \big(F(a) \cup G(a)\big) \cap H(a) \\ &= \big(F(a) \cap H(a)\big) \cup \big(G(a) \cap H(a)\big). \end{aligned}$$

From the RHS, we have that

$$(F,A) \cap_R (H,A) = (P,A) \text{ and } P(a) = F(a) \cap H(a).$$

Similarly, $(G,A) \cap_R (H,A) = (Q,A)$ and $Q(a) = G(a) \cap H(a)$.

Consequently, we have that

$$M(a) \cap H(a) = N(a) = P(a) \cup Q(a).$$

Thus, $\big((F,A) \cup_R (G,A)\big) \cap_R (H,A) = \big((F,A) \cap_R (H,A)\big) \cup_R \big((G,A) \cap_R (H,A)\big)$.

Having considered soft ideals, we now present the concept of homomorphisms between soft semigroups namely; soft homomorphisms.

Let S and T be two semigroups and let $(F,A)$and (G,B) be two soft semigroups such that $\alpha : S \to T$ and $\beta : A \to B$ are two functions. Then (α,β) is a soft homomorphism and (F,A) is soft homomorphic to (G,B) if the following conditions are satisfied;

i. α is a homomorphism from S onto T

ii. β is a surjective mapping from A to B

iii. $\alpha(F(a)) = G(\beta(a))$ for all $a \epsilon A$.

It is important to note that if α is an isomorphism from S to T and β is an injective mapping from A onto B then (α,β) is called a soft isomorphism and $(F,A) \cong (G,B)$.

Lemma 3.7. Let S and T be two semigroups and let (F,A) and (G,B) be two soft semigroups such that $(\alpha,\beta)\colon (F,A) \to (G,B)$ is a soft homomorphism. If (F,A) is soft ideal over S, then (G,B) is a soft ideal over T.

Proof. Obviously, (F, A) is a soft ideal over S which implies that $F(a)$ is an ideal of S. Now since (α, β) is a soft homomorphism, then we have that for each $b \epsilon B$ there exists $a \epsilon A$ such that $\beta(a) = b$.

Consequently, we have that

$$G(b) = G(\beta(a)) = \alpha(F(a)) .$$

Since $F(a)$ is an ideal of S, this implies that $\alpha(F(a))$ is an ideal of $H(\beta(b))$.

Thus, $G(b)$ is an ideal of $H(\beta(b))$ for all $b \epsilon B$.

Hence (G, B) is a soft ideal over T.

Lemma 3.8. Let S and T be two semigroups and let (F, A) and (G, B) be two soft semigroups such that (G, B) is a soft ideal of (F, A) over S. Then for a soft semigroup (H, C) over T, $(\alpha(G),\ \beta(B))$ is a soft ideal of (H, C) and $(\alpha, \beta) : (F, A) \to (H, C)$ is a soft homomorphism.

Proof. It can be easily seen that $G(b)$ is an ideal of $F(b)$ for all $b \epsilon B$, so we have that $G(b) \subseteq F(b)$ which implies that $\alpha\big(G(b)\big) \subseteq \alpha\big(F(b)\big) = H\big(\beta(b)\big)$.

Obviously, $\alpha\big(G(b)\big)$ is an ideal of T since $G(b)$is an ideal of $F(b)$.

Consequently, $\beta(B) \subseteq C$ since β is a function from A onto C.

Thus, $(\alpha(G),\ \beta(B))$ is a soft ideal of (H, C).

Remark 3.9. Suppose $(\alpha, \beta) : (F, A) \to (G, B)$ and $(\gamma, \theta) : (G, B) \to (H, C)$ are soft homomorphisms, then the soft composition of (α, β) and (γ, θ) is defined as

$$(\alpha, \beta) \circ (\gamma, \theta) = (\Gamma, \lambda) \text{ where } \Gamma = \alpha \circ \gamma \text{ and } \lambda = \beta \circ \theta.$$

We conclude this section by characterizing soft regular semigroups. It is known that an element a of a semigroup S is said to be regular if there exist an element $x \epsilon S$ such that $axa = a$. If every element of a semigroup S is regular then S is said to be a regular semigroup.

Now with our knowledge of soft ideals and regular semigroups, we present the following result.

Theorem 3.10. Let (F, A) and (G, B) be two soft semigroups over a semigroup S and define the operation $\circledast$ as $(F, A) \circledast (G, B) = (H, A \times B)$, where $H(a, b) = F(a) \circledast G(b), a \epsilon A$, $b \epsilon B$ and $A \times B$ is the Cartesian product of A and B. Then S is a regular semigroup if and only if $(R, A) \circledast (L, B) = (R, A) \wedge (L, B)$ for every soft left ideal (L, B) and soft right ideal (R, A) over S.

Proof. For the direct part of the proof, we know that $(R, A) \circledast (L, B) = (H, A \times B)$ where H is a function $A \times B$ to $P(S)$ defined by $H(a, b) = R(a) \circledast L(b)$.

Obviously, $(R, A) \wedge (L, B) = (K, A \times B)$, where K is a function from $A \times B$ to $P(S)$ defined by $K(a, b) = R(a) \cap L(b)$.

Consequently, $A \times B \subseteq A \times B$ and we have that

$$R(a) \circledast L(b) \subseteq R(a) \circledast S \subseteq R(a) \text{ and } R(a) \circledast L(b) \subseteq S \circledast L(b) \subseteq L(b).$$

Thus, $R(a) \circledast L(b) \subseteq R(a) \cap L(b)$ for all $a \in A, b \in B$ so that $(H, A \times B) \subseteq (K, A \times B)$.

Now let $x \in R(a) \cap L(b)$. Since S is regular and $x \in S$, then there exists $y \in S$ such that $xyx = x$. Since $x \in R(a)$ and $yx \in L(b), xyx = x \in R(a) \circledast L(b)$ which implies that $(R, A) \wedge (L, B) \subseteq (R, A) \circledast (L, B)$. Hence, $(K, A \times B) \subseteq (H, A \times B)$ so that $(R, A) \circledast (L, B) = (R, A) \wedge (L, B)$.

Conversely, let $A = B = S$ and R be a function from A to $P(S)$. Define $R(x) = xS^1$, for all $x \in S$ and let L be a function from B to $P(S)$, defined by $L(x) = S^1x$, for all $x \in S$. This implies that (R, S) is a soft right ideal and (L, S) is a soft left ideal over S.

So we have that $x \in R(x) \cap L(x) = R(x)L(x) = xS^1S^1x \subseteq xS^1x$.

Hence, we have that S is a regular semigroup and the theorem is proved.

Let S be a semigroup and (F, A) be a soft semigroup over S. Then (F, A) is said to be a soft regular semigroup if for each $a \in A$, $F(a)$ is a regular subsemigroup of S.

It is important to note that regularity of a soft semigroup does not necessarily imply regularity of the semigroup. This is shown in the example below.

Example 3.11. Consider $S = \{m, n, o, p\}$ be a semigroup defined by the Cayley's table below

$\star$	m	n	o	p
m	m	m	m	m
n	m	m	m	m
o	m	m	m	m
p	m	m	m	p

It can be easily seen that S is not a regular semigroup. Now let $A = \{x, y\}$ be a set of parameters such that $F(x) = \{m\}$, $F(y) = \{m, p\}$. Then (F, A) is a soft regular semigroup over S since $F(x)$ and $F(y)$ are regular subsemigroups of S.

4. Conclusion

In this work, we have presented some semigroup properties of soft sets other than the ones in the literature. We have also revisited some basic operations in soft set theory and proved some new results. Defining some new concepts can be viewed as a positive contribution towards an advancement of semigroup theory.

This paper also motivates future research especially as regards to applications of soft semigroups.

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