A Survey of Impact and Citation Indices: Limitations and Issues

Majdi Maabreh[1] and Izzat M. Alsmadi[2]

[1]*Computer Center, Hashemite University, Zarqa, Jordan*
[2]*CIS Department, IT Faculty, Yarmouk University, Irbid, Jordan*
maabreh3110@yahoo.com, ialsmadi@yu.edu.jo

Abstract

Research projects can be evaluated through evaluating the research publications produced through those projects. Research publications are evaluation using impact factors and citation indices. There are several citation indices that are proposed and existed to assess the value of a research publication or the research impact of an author or a journal. In this paper, an extensive survey is conducted to evaluate the majority of the citation indices. Using examples, we demonstrated some of the limitations and problems with those indices. The evaluation showed that there is a need for more sensitive and comprehensive citation indices that can take into considerations all the factors that may impact a research publication or author. Survey also showed that the majority of citation indices heavily depend on the "H-core" focus on most cited papers which exist in H-index and most successive indices.

Keywords: *Citation index, impact factor*

1. Introduction

In the last few years, several research and publication papers related to research indices were proposed to assess the quality of the academic research publications. Each one of those indices has its own strengths and weaknesses. The idea of having research indices started when (Hirsh, 2005) proposed the H-index. Although the H-index has many limitations and seems biased or unfair in many cases, the other proposed indices such as: G-, H(2)-, HG-, Q2 -, AR-, M-quotient, M-, W-, Hw- ,E-, A-, R- , W-, J-index, etc. considered H-index as a suitable base to produce those other indices with some behavioral enhancements in order to overcome its limitations. In fact, all the other indices are calculated based on the number of citations (which was originally proposed in H-index) which the authors' papers received. The differences between those indices can be shown through how the index deals with the citations number, as in H-index, G-index, W-index, or in adding new attributes such as time, average…etc as in Contemporary H-index, M-quotient, and AR- index. The subject of limitations in research indices is still evolving and with all proposed indices, there are still limitations and weaknesses. Moreover, the large number of available indices may lead to the dispersion of the evaluation, and therefore produce differences in values among research communities or even countries. Sites and tools that are interested in the evaluation of researchers and research publications may have to calculate and display all the indices, and this may cause two issues: First, the large number of indices, if used, may clutter pages and make them unreadable. In addition, and since most likely values will be different among those indices, and in some cases they may even contradict with each other, such information will be misleading to the reader rather than being helpful or informative.

Research papers and publications are important indicators for the ability of an author or an education community to conduct research projects in the different human science fields. In general, the number of publications and the increase in this number is a direct indicator of the size or the volume of research activities for a particular author or university. Nonetheless, the number of publications merely, is showed to be a limited indicator to show the impact of those publications. The number of citations for a particular paper is shown to be more relevant and important in comparison to the number of publications. This is why early citation indices such as H-index and G-index gave more weight and important to the number of citations in comparison to the number of publications.

Consider the examples in Table 1 where number of publications and citations are shown. In case 1, H-index is 4 (The 4th column is the last column where, citations are greater than or equal publications' sequence). G-index is 5 shown by the row "Comp" where the 5th column is the last column where Sum-C is greater than or equal Square (Sequence) (i.e. 35 >= 25 but 35 not >= 36 in 6th column). In case 2 of Table 1, numbers show that one article with a high number of citations can distant the G-index from the H-index (H-index = 2 and G-index =8). Because of using the cumulative summation; the number of publications of a researcher does not limit the G-index value. The highly cited publication (i.e. Big hits) may also affect the value of G-index. This is can be shown in case 2 where some dummy articles (i.e. 7 and 8 in case 2) with zero citations should be added in order to complete the G-index calculations.

Table 1. H and G Index Demonstration

Case_1	Publication_ID	1	2	3	4	5	6			
	Citations	13	9	6	4	3	0			
	Sum-C	13	22	28	32	35	35			
	SQR	1	4	9	16	25	36			
	COMP.	1	1	1	1	1	0			
Case_2	Publication_ID	1	2	3	4	5	6	7	8	9
	Citations	68	4	2	2	1	0	0	0	0
	Sum-C	68	72	74	76	77	77	77	77	77
	SQR	1	4	9	16	25	36	49	64	81
	COMP.	1	1	1	1	1	1	1	1	0

A survey of more than 10 citation indices starting from H-index indicates that there are some problems with those citation indices. For example, one of the major problems in H-index and all later indices that depend on it, is the focus on the "H-core" papers. Those are the papers of a particular author that are getting the highest number of citations relative to the rest of the author publications. This is as those citation indices are designed per author and not per paper. Those indices are shown to be insensitive for publications outside the "H-core" publications. In addition, investigations and evaluation of those indices showed that those indices are also less sensitive to the increase of the number of citations once the number of citations reaches a high volume. This is somewhat similar to calculating the average or the GPA for students where once the student accumulates a high number of passed courses, the GPA becomes less sensitive to a high or low grade in a particular course. Other problems in the citation indices include some other aspects of the paper and the author that are ignored in previous citation indices. Examples of those attributes include the age of the published paper and the scientific age of the author. For example, a paper that is published last year and has 20

citations should be given a more weight as a paper that was published 10 years ago and yet is having only 10 citations.

The rest of the paper is organized as the following: The next section summarized related work to the subject of this paper summarizing some papers that discuss the issues and limitations of citation indices. Section three will include the goals and approaches followed in this paper. Section four includes the experiment and analysis. The paper is concluded with a summary and conclusion.

2. Related Work

The subject of this paper is a multi disciplinary subject that can be part of education, algorithms, data mining and possibly some other research areas. In this paper our focus is on evaluating the limitation of the current paper and author impact factors. The papers that will be selected in this section are selected based on the scope and the subject of the paper.

Research publications are real indicators of an active institute in one or more scientific fields. Disseminating the scientific ideas among researchers through (journals, conferences, books…etc.) make those ideas visible to the public and available for possible improvements and extensions. However, it is not necessarily that the large number of research publications in a scientific field indicates its development and strength. Evaluating the quality of publications for fitness is not always consistent. It depends on several factors including the nature of the field, the gap between the academia and the industry, the interests of the individuals and the public or the governments, etc. Analysis of the quality of scientific production dates back to the fifties of the past century when Eugene Garfield suggested focusing on quality as well as the number of research publications [1].

Usually, the publications which have a large number of citations mean that they include influential and significant ideas between its lines which tempted other researchers to refer to it. Conversely, those which have few numbers of citations may have no significant ideas to follow up with.

In the most recent years, several research and publications related indices were proposed to assess the quality of the academic research publications. Each one of those indices has its own strengths and weaknesses.

The idea of having research indices started when (Hirsh, 2005) proposed the H-index, designed to measure the impact of research publications of a researcher and then estimate the author influence [2]. Hirsh defined the H-index as: "*A scientific has index h if h of his or her N_p papers have at least h citations each and the other (N_p – h) papers have <= h citations each*". For example, if a researcher have 5 publications which were cited as 5, 5, 4, 2, 1 times, then he/she will have an H-index of 3, as there are just 3 (*H-core*) out of 5 publications have more than 3 citations each (*H* value) and the two other publications have citations less than the H value each. Since, the H-index was gained an acceptance in the research community as an easy to assess and collect index or metric.

The H-index was considered better than the previous values such as number of publications, number of citations, citation per publication ratio and number of high success publications, where these values take only one dimension or factor of the picture. Despite its spread and usage the H-index is shown to have several significant limitations.

Several research papers discussed those limitations and proposed solutions for them. A number of these limitations were discussed by Hirsh himself. For example he mentioned that the H-index should not be used to compare researchers from different fields or of different ages. Other issues were discussed later in literature such as the dependency of H-index on the researcher's age (Hirsh, 2005; Kelly and Jennions, 2006) [3] and even the case that we

mentioned in the introduction section where the citations number is increased for those paper located at H-core and yet there is no difference in H-index value (Egghe, 2006) [4].

However, several publications and impact related research papers considered H-index as a suitable base to produce those other indices with some enhancements of its behavior in order to overcome its limitations. (Egghe 2006) proposed the G-index for publications assessment as an improvement to the H-index. According to Egghe, "*If a set of articles ranked in decreasing order of the number of citations that they received, the G-index is the unique largest number such that the top g articles received together at least* g^2 *citations*".

The G-index comes to be more expressive with highly cited publications (e.g. H-core publications) in comparison to H-index, so that the increasing in the number of citations for those belongs to H-core will be taken into account in the G-index. Generally, the G-index is calculated in the same way of the H-index. As in the example of H-index above, the sequence number of publications will be 1, 4, 9, 16, 25 (i.e. the squares of citations) and the cumulative numbers of citations are 5, 10, 14, 16, and 17. Then the G-index is equal to 4, as the last value of cumulative column is 17 which is not greater than 25 in the first column. Because of using the cumulative summation; the number of publications of a researcher does not limit the G-index value. The highly cited publication (i.e. Big hits) may also affect the value of G-index.

Based on the same behavior of calculating H and G indices, (Kosmulski, 2006) proposed the H(2)-index which gives also more attention to the highly cited research publications (H-core publications) as G-index does [5]. A scientist's H(2)-index is calculated as the highest natural number such that his H(2) most cited papers (i.e. for the subject author) received each at least Square of H(2) citations. As the above example, the Auth_1 has h(2)-index of 2 means that at least two papers of this authors attracted at least 4 citations each.

(Wu Q., 2010) proposed W-index in the same manner as a proposed significant improvement of the H-index. In the W-index, If A: papers of a researcher's papers have at least 10*A citations each and the other papers have fewer than 10(A+1) citations, then author W-index is A [18].

There are also several other indices were proposed which concentrate on the publications that were located at (H-core) in its calculations. For example, (Jin, 2006) defined the A-index as the average citations number for those publications in the H-core, which is 14/3=4.6 for the author example described previously in literature review [6]. The R-index (Jin et al., 2007) was defined as the square root of the total summation of H-core publications citations (e.g. SQRT(14)=3.74 for the author in the above example). Taken into account the publication age, (Jin et al., 2007) also enhance the R-index by dividing the number of citations of each publication over its age, which is known as R-index [25].

(Bornmann et al, 2008) also defined the M-index as the median value of H-core citations (e.g. 4 for the example above) [7]. The E-index proposed in (Zhang, 2009) concentrated also on the H-core contents, where the only highly cited publications are taken into account in its calculation. The E-index defined as SQRT (summation (citations of core paper $_i$ – h^2)).

In an effort to combine indices, (Alonso et al, 2010) proposed the HG-index as aggregation the indices: H and G, where the latter comes to overcomes the former limitations. The results showed that the combined index is able to ranked researchers better than H and G indices separately. Similarly, the q^2-index (Cabrerizo et al, 2010) was defined as an aggregation of H- and M- indices. Where the size of H-core is indicated by H-index combined with the H-core contents impact which indicated by M-index. According to authors, applying this index on real world examples showed the effectiveness of its results.

According to (Bornmann L. and Marx W., 2011) [11] and (Costas R. and Bordons M., 2007), the H-index will never be decreased. It could be considered as a firewall for those researchers who already get a high H-index because of their few success works. If a particular

researcher is inactive or a low producer, his/her H-index will be only increased and not decreased. New active researchers will not be also compared due to their few works because of the time issue. For those reasons, other attributes related to the time issue such as researcher, publication, or citation age were taken into account to enhance H-index. (Hirsh, 2005) proposed the *m* factor as an enhancement to the original H-index, where the value of original H-index will be divided by the number of years from the first publication to the year of index calculation (Researchers' age).

In addition, (Sidiropoulos et al, 2007) proposed three different indices. The first one is the contemporary H-index where the article age is taken into account in order to distinguish active papers and researchers [13]. It is defined as "A researcher has contemporary H-index hc, if hc of its Np articles get a score of Sc(i) >= hc each, and the rest (Np-hc) articles get a score of Sc(i) <= hc". The index of such article can be decreased in some scenarios. Second, trend H-index, where the citations' age affects the index value. The articles which are cited for a long period of time are considered as better than those cited for few years after its publication date.

The trend H-index was defined as "A researcher has trend H-index HT, if HT of its Np articles get a score of St(i) >=ht each, and the rest (Np-ht) articles get a score of St(i) <=ht each." Third, as the researchers may not have the same number of publications, the normalized H-index was proposed in order to enhance the fairness of original index. It is defined as: "A researcher has normalized H-index hn=h/Np, if h of its Np articles have received at least h citations each, and the rest (Np-h) articles received no more than h citations".

Conversely for those concentrate on the H-core and H-index, (Ye and Rousseau 2009) defined the rest of publications (excluding H-core) as (H-tail) [14]. A tail-core ratio is defined as a time function equal to CT(t) / CH(t), where CT(t) is the number of citations for tail articles and CH(t) is the number of citations for articles belonging to H-core in the same period of time t. The K-index was also defined based on tail-core ratio and the impact of publications (C/P), such that: K-index= (C(t)/P(t)) / Tail-core ratio(t).

The practical experiment shows that if H-tail is increased, K-index value is decreased while H-index is increased. (Bornmann and mutz, 2010) divided the publications' citations into three parts: the highly cited papers h^2- upper index, h2-center index for H-index area and the h2-lower index for those publications that are not included in h calculations [19].

Based on the value and the approach of H-index, (Egghe and Rousseau 2008) replaced the column of sequence number of publications by the citations' weight in the HW-index [15]. The number of citations of each publication is divided by H-index. The HW-index equals to the square root of the summation of citations for those publications which have citations more than citations weights.

(Prathap, 2010) benefits from the average citation per research article to propose the mock H-index (HM) [16]. The mock index covered all citations (C) for all publications (P). There are no cores in the calculations of mock index. It is defined as: HM-index=((C)2/P)1/3. Similarly, tapered-index (Anderson et al, 2008) takes all publications and its citations to form the (Ferrers graph) [17]. The H-index is then equal to the length of the side of Durfee square which is calculated as: "The largest completed (filled in) square of points in the upper left hand corner of the Ferrers graph".

In a study that tried to see if high values of indices represent significant papers and researchers, (Yin 2011) conducted a study focused on the chemical engineering field of science [22]. He compared results from different indices such as: H-Index and Eigenfactor. The findings of the paper proposed the combination of such indices to best present realistic situations. (Waltman and Eck 2011) paper made some investigations on the limitations of the

H-index [23]. They mainly argued that H-index is used to measure the overall scientific of a set of publications without focus on measuring the average scientific impact per publication (i.e. size-independent indications). The new index that we proposed in this paper tried to combine both criteria in assessing the overall contribution of an author while also giving credit or values for papers independent from each other.

In (Burrell 2009), the author conducted a comparison assessment between several citation indices specially those that criticized the H-index and proposed enhanced indices [24]. The general formula that they found comparing three indices ($g \geq h \geq h(2)$), is usually true for many indices which indicates that some indices can subsume other indices or that they are considered as "special cases" of the larger indices.

3. Citation Indices: limitations and Issues

Every proposed index can have strengths and weaknesses. More specifically, every index can show or highlight a perspective of the paper or the other, while partially ignoring the other aspects. In this section, some of proposed indices' weaknesses with artificial examples will be discussed.

3.1 H-index

H-index is considered as the common measure used in different interested websites and tools. However, this index went through several assessments. (Bornmann and Marx, 2011) and (Bordons and Costas, 2007) summarized many of H-index weaknesses. One issue related to the H-index calculation and that there is no logical connection between number of citations and publication sequence. In addition, new authors have a problem with H-index as they have no or low index value due to time constraints. As the value of the H index will never decrease, then some of researchers may depend on high values and therefore their real production or activity will decrease with time.

The publications outside H-core were ignored. (Ye and Rousseau, 2009) paper proposed the K-index to overcome the H-index limitations in dealing with the rest of publications (i.e. h-tail for those papers not in the H-core). Moreover, H-index does not take the actual number of citations; the content of H-core is not sensitive with more citations, (Jin, 2007 and Egghe, 2006). Table 2 shows an artificial example to demonstrate H-index weaknesses.

Table 2. An Example for H-index Weaknesses

	Authors/ Citations			
PaperID	A	B	C	D
1	15	100	110	10
2	11	60	55	10
3	5	22	40	10
4	4	3	13	9
5	4	3	13	9
6	3	3	2	0
7	3	3	1	0
8	2	2	1	0
9	0	1	1	0
10	0	0	1	0
TOTAL	47	197	237	48
H-index	4	3	5	5

As shown in Table 2, for author A, the H-index stopped on publication 4. There is no logical reason to exclude the publication 5 since it has the same number of citations (i.e. 4). Another issue, the H-index indicates that that author B has less research impact that author A, while the Table shows that Author B has more successful papers (in terms of citations). The same case can be said between authors C and D. This means that H-index maybe misleading in some scenarios and produce contradictory results. In addition, the distribution of citations over publications was also missing in H-index calculations. For what is called h-tail, there is no logical base to exclude from H-index calculations. If the author has more than 10 publications with more than 10 citations each, is the tail content in such case useful or not?

3.2 G-index

(Egghe, 2006) proposed the G-index, which is now a major index in addition to the H-index. In trying to overcome the H-index limitations, G-index was proposed based on the H-index behavior with some enhancements. However, the "big-hit" problem of G-index was linked with its calculation. Moreover, as in H-index, there is no logical connection between the cumulative citations with the square value of publication sequence. The factious publications may be needed to complete the G-index calculation, as in case of Author B and C in Table 2 above. In a further issue, which can be seen in Table 2 above, where the authors: A and D have 6 and 7 as G-index respectively, what if more information about authors' age was added? For example the academic research ages for the two authors were: 3 and 10 years respectively, has the author A less effect or activity than author D? In addition, as in H-index, it may not be used to compare researchers' productions of different ages, as in the case for the new researchers, due to time constraints.

3.3 H(2)-index

Table 3 shows artificial examples to demonstrate limitations and issues related to H(2)-index. First issue which is inherited from H-index, although the citations for success works are increased the H(2) is not. The citations distribution will not also impact or change the index value. Although the H-index takes all publications of author A into account, however, the H(2)-index creates a new tail in a trial to focus on the "tail" publications in comparison to the "core" publications that get the focus in H-index case. If we focus on authors A and F, do their works have the same tail weight to be neglected. It seems that H-index deals more fairly with this issue in comparison with H(2) index.

How many citations are needed to increase H(2)-index? H(2)-index indicates that Authors: A, B and C are at the same level (i.e. 7). Then Author A needs at least 8 citations for papers 7 and 8 (i.e. 4 citations for each) to get H(2)-index=8. On the other hand, Author B needs at least 112 citations for his papers from 1 to 8 (14 citations for each) to get H(2)-index= 8. If they have the same impact or level then why now they need a different level of contribution to move from the same level to a new identical level? Another serious problem can be demonstrated using the case of author D, H(2)-index indicates that author D has more influence than the others (H(2) index of 9 relative to 7 for all previous authors). However, in terms of citations, the papers of: A, B, and C seem more popular. In the case of the new authors, E and F, Author E has only one work with one citation, while Author F has 5 publications with 3 citations each, the H(2)-index is the same for both(i.e. 1). Although H-index has weakness with new researchers, it still seems more balance with them than H(2)-index.

Table 3, H(2)-index Examples

		Authors					
Paper_ID	Square(ID)	A	B	C	D	E	F
1	1	250	400	50	88	1	3
2	4	220	390	50	86	x	3
3	9	200	300	50	84	x	3
4	16	190	250	50	84	x	3
5	25	140	240	50	83	x	3
6	36	100	200	50	83	x	x
7	49	60	60	50	83	x	x
8	64	60	60	50	82	x	x
9	81	55	55	50	81	x	x
10	100	55	55	50	10	x	x
11	121	50	50	50	10	x	x
12	144	50	50	50	9	x	x
13	169	50	50	40	9	x	x
14	196	49	40	40	2	x	x
15	225	48	40	30	1	x	x
16	256	45	40	30	1	x	x
17	289	40	35	20	0	x	x
18	324	35	30	10	0	x	x
19	361	35	15	1	0	x	x
20	400	25	10	0	0	x	x
TOTAL		1757	2370	771	796	1	15
H-index		20	18	17	10	1	3
H(2)-index		7	7	7	9	1	1

3.4 W-index

Similar to H and H(2) indices, W-index does not take into account the number of citations in the core index. For example, author B (Table 4) has 2500 citations for W-core while Authors: C and D have: 52, 42 citations respectively, and yet they have the same W-index value. Again, neglecting the rest of the works (outside the index core) raise a question, why such contributions are ignored?

The new authors need 10 citations for each new paper to enter in the W-index calculation; otherwise, the impact of this work for the author is zero even if they have 1000 publications with less than 10 citations each, as in the case of author A. In addition, the number of publications is not taken into account. For authors: D and, they get W-indices of 2 and 4 respectively. W-index then indicates that author E has a higher impact than authors: A, B, C and D, which contradict with numbers shown in Table 4.

The total number of citations has no effect in W calculations. Looking at the pairs: number of citations, and w-index for the examples in Table 4: (114, 0), (2965, 2), (469, 2), (42, 2) and (160, 4), we can see that there is no regular connection between the number of citations and the index values. In addition, this index is ignoring some other related factors such as: author age or publication age. Similar to the previously discussed indices, we cannot use W-index for comparing authors of different ages.

Table 4. W-index Examples

		Authors				
PaperID	W-weight	A	B	C	D	E
1	10	8	1500	26	22	40
2	20	8	1000	26	20	40
3	30	8	25	25	X	40
4	40	7	24	25	X	40
5	50	7	24	25	X	x
6	60	7	24	24	X	x
7	70	6	24	24	x	x
8	80	6	24	24	x	x
9	90	6	23	23	x	x
10	100	6	23	23	x	x
11	110	5	23	23	x	x
12	120	5	23	22	x	x
13	130	5	22	21	x	x
14	140	5	22	21	x	x
15	150	5	21	21	x	x
16	160	4	21	20	x	x
17	170	4	21	20	x	x
18	180	3	21	19	x	x
19	190	3	21	19	x	x
20	200	2	21	19	x	x
21	210	2	20	10	x	x
22	220	1	19	5	x	x
23	230	1	19	4	x	x
TOTAL		114	2965	469	42	160
W-index=		0	2	2	2	4

3.5 A-index

The A-index comes to concentrate on the H-core content. However, as seen from the example below that A-index still has many limitations. First of all, as the A-index depends on the value of H-index, it creates a strong dependency on the H-index. The rest of publications that do not belong to H-core are neglected as a result of this dependency. Table 5 below shows artificial examples to demonstrate A-index issues. As seen from the examples, the distribution factor in H-core is not taken into account (e.g. authors: A and B). While both authors: A and B have 3060 citations, 3000 out of them belong to the H-core. While the author A has more popular publications than author B who depends on only two success papers, the A-index shows them to have the same index value. In another limitation which can be demonstrated using the cases of authors: authors C and E, the former has 19 publications in H-core with 392 citations, while author E has only 2 publications with 42 citations? According to A-index formula the author C has 20.632 of A-index and E has 21, which is unfair and unacceptable. The same case can be demonstrated with authors: H and I. Moreover, in the cases of authors: F and G, the former has only 2 publications with 40 citations each in H-core and the second has 19 publications with 760 citations in H-core. The citation numbers equal 40 each for publications in H-core. However, the A-index indicates

that they have the same effect or impact. In another issue, if the author F gets 10 more citations to the first publication, then the A-index will be 45. This means that he got a higher index in comparison to author G.

Table 5. A-index Artificial Examples

	Authors							
PaperID	A	B	C	E	F	G	H	I
1	155	1548	22	22	40	40	102	101
2	155	1010	22	20	40	40	102	x
3	155	30	22	x	x	40	102	x
4	155	30	21	x	x	40	101	x
5	150	30	21	x	x	40	101	x
6	150	30	21	x	x	40	101	x
7	150	30	21	x	x	40	101	x
8	150	30	21	x	x	40	101	x
9	150	30	21	x	x	40	101	x
10	150	24	20	x	x	40	100	x
11	150	20	20	x	x	40	100	x
12	150	20	20	x	x	40	100	x
13	150	20	20	x	x	40	100	x
14	150	22	20	x	x	40	100	x
15	150	21	20	x	x	40	100	x
16	150	21	20	x	x	40	100	x
17	145	21	20	x	x	40	100	x
18	145	21	20	x	x	40	100	x
19	145	21	20	x	x	40	100	x
20	145	21	19	x	x	10	10	x
21	20	20	10	x	x	10	10	x
22	20	20	5	x	x	10	10	x
23	20	20	4	x	x	10	10	x
TOTAL	3060	3060	430	42	80	800	1952	101
H-index=	20	20	19	2	2	19	19	1
sum H-core	3000	3000	392	42	80	760	1912	101
A-index=	150	150	20.63	21	40	40	100.632	101

3.6 R-index

R-index concentrates also on the content of H-core. Author B case in Table 6 shows the impact of biasing such index through a big hit. This is due to the distribution factor which does not affect the index value (e.g. in comparison between authors: A and B in Table 6). In the case of authors C and E, the R-index will not increase in regular or fair slope. When 5 citations are added to C's first paper the index is changed by 0.453 and with only 0.157 for author E with the same 5 citations. With the large number of citations, the increment in the index value will be very small. For example, for authors: F and G, the former needs only 10 citations of the first paper to increase R-index by 1.026 while author G needs 33 citations to the first paper to increase the R-index by 1.027.

In addition to the problem of dependency on H-index value, the rest of publications which do not belong to H-core were also ignored. Another issue raised in R-index which is related to time, what if information such as academic research age was added? If (for example) author A has 10 years old and author B has 30 years old, can we depend on R-index in decision making?

Table 6. R-index Artificial Examples

	Authors							
PaperID	A	B	C	D	C +5	E +5	F	G
1	70	420	8	170	13	175	6	200
2	66	21	8	55	8	55	5	15
3	62	21	7	12	7	12	4	11
4	60	19	5	12	5	12	4	10
5	59	18	4	4	4	4	3	6
6	59	17	2	1	2	1	0	1
7	55	17	1	1	1	1	0	0
8	55	17	1	1	1	1	0	0
9	44	16	X	1	x	1	0	0
10	33	16	X	1	x	1	x	X
11	24	15	X	1	x	1	x	X
12	21	15	X	1	x	1	x	X
13	19	15	X	0	x	0	x	x
14	15	15	X	0	x	0	x	x
15	15	15	X	x	x	x	x	x
16	15	15	X	x	x	x	x	x
17	14	14	X	x	x	x	x	x
18	13	13	X	x	x	x	x	x
19	10	2	X	x	x	x	x	x
20	10	2	X	x	x	x	x	x
21	10	2	X	x	x	x	x	x
22	9	1	X	x	x	x	x	x
23	2	1	X	x	x	x	x	x
Citations	740	707	36	260	41	265	22	243
H-index=	15	3	4	4	2	19	20	21
sum H-core	657	657	28	249	33	254	19	242
R-index	25.632	25.63	5.29	15.78	5.745	15.93	4.359	15.55

3.7 E-index

Similar to those indices which depend on H-index, the E-index has also some limitations related to its calculations. The dependency issue, that we cannot calculate E-index without the value of H-index. The neglected publications are not considered in E-index calculations . Seriously, the value of E-index can be Zero, as shown in (Table 7) for the case of author A. Although the author has 10 publications with 10 citations each, however the E-index indicates that the author index is low. The E-index does not also take into account *the distribution* of citations in H-core, as seen in Table 7 in the case of authors: B and C. While author C has more popular publications, he/she get the same E-index value as author B who depends on one success publication in comparison with other publications' citations. In the case of authors: D and E, if both of them gain 5 more citations to their first paper, then E-index value will be 6.708 and 21.517 respectively. This means that with the same number of citations, the impact on the two authors was different based on the original number of citations. The E-index value is increased by 0.383 for author D and by just 0.116 for author E. In addition, what if author B has 5 years of academic research age and author C has 20 years? Can we depend on this index to evaluate the research impact of those two authors fairly?

Table 7. E-index Artificial Examples

	Authors				
PaperID	A	B	C	D	E
1	10	25	15	33	300
2	10	6	12	8	140
3	10	6	10	8	19
4	10	5	10	7	18
5	10	5	9	4	6
6	10	3	2	2	5
7	10	1	2	2	5
8	10	0	0	0	4
9	10	0	0	0	3
10	10	0	0	0	0
Sum	100	51	60	64	500
sum H-core	100	47	47	56	483
H-index	10	5	5	4	5
E-index	0.000	4.69	4.69	6.32	21.40

3.8 M-index

As many other indices, the M-index depends on the H-core contents. The rest of publications which do not belong to H-core are ignored. In addition, the citation distribution will not be taken into accounts and the increment in H-core citations may not affect the value of M-index. Based on the median value, H-core contents may increase the attention to the success publications of such author. The examples in Table 8 can demonstrate many issues with M-index. For example, in the case of authors: A and B, the M-index indicates that author A has more impact value or influence than author B, which is (as seen from the example) an incorrect impression, since author B has more success publications than author A. Second, the M-index returns the same value for authors: B, C and D while in reality they should not.

Moreover, the behavior of M-index suffers from "Sudden Jump". For example if author B in Table 8 gains 100 more citations to his/her first paper, then the M-index will not be affected. However if the fourth paper gains 5 more citations the M-index will be 12. As both papers belong to the H-core, so, it is strange to have such different behavior for somewhat identical papers. In addition, author's age is a factor that is neglected in this index similar to many previously mentioned ones.

Table 8. M-index Artificial Examples

	Authors			
PaperID	A	B	C	D
1	10	150	170	7
2	10	100	7	7
3	10	88	7	7
4	7	7	7	7
5	7	7	6	6
6	5	7	6	6
7	5	7	4	4
8	1	4	4	4
9	0	1	2	2
10	0	0	0	0
TOTAL	55	371	213	50
sum of H-core	44	359	203	40
M-index	10	7	7	7

3.9 HG-index

Beside the dependency on H-index, the HG-index adds new dependency on G-index. This solves the problem of "Big-hits" and the distribution issue as seen in Table 9 for authors: B and C. Nonetheless, some problems can still be seen. For example, for authors: C and D, although the author D has 15 more citations to his/her first paper, nonetheless the HG-index gives them both the same value. Another issue is related to the sensitivity of HG-index, the HG-index becomes difficult to change with the large number of citations due to the usage of the square root function, inherited from G-index.

Table 9. HG-index Artificial Examples

	Authors			
PaperID	**A**	**B**	**C**	**D**
1	10	200	55	70
2	7	9	40	40
3	7	8	33	33
4	6	8	22	22
5	4	8	17	17
6	3	5	17	17
7	2	1	15	15
8	1	0	15	15
9	0	0	15	15
10	0	0	10	10
TOTAL	**40**	**239**	**239**	**254**
H-index	**4**	**5**	**10**	**10**
G-index	**6**	**15**	**15**	**15**
HG-index	**4.9**	**8.66**	**12.247**	**12.247**

3.10 AR-index

The AR-index takes into account the H-core publications' age which adds more advantage to those active and power authors. However, the AR-index still, similar to many other indices, depends on H-index and takes only the contents of H-core in its calculations. The index sensitivity is also another issue with AR-index especially with large number of citations due to the usage of square root.

Table 10. AR-index Artificial Examples

Authors	PaperID	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	TOTAL	Age	Cit/Age
A	1	1	7	8	4	0	0	0	0	0	0	20	10	2
	2	3	12	0	0	0	0	0	0	0	0	15	10	1.5
	3	0	6	4	0	0	0	0	0	0	0	10	10	1
													SUM	**4.5**
													AR-index	**2.121**
B	1	1	2	4	3	2	2	2	1	2	1	20	10	2
	2	3	3	1	1	1	1	1	2	1	1	15	10	1.5
	3	0	0	0	0	4	2	2	1	0	1	10	10	1
													SUM	**4.5**
													AR-index	**2.121**

In Table 10, the authors: A and B have three publications with 20, 15 and 10 citations respectively with 10 years author age for each. Another issue to mention is about how the publications get their citations? In the case of author A, the publications were popular after few years of their production and then go into a calm stage. In the case of author B, his/her publications are more active in terms of citations to the year of index calculation (i.e. 2011). The AR-index returns the same index value for both authors.

3.11 M-quotient

M-quotient index takes the time issue in consideration. M-quotient considers the author academic age beside the value of H-index. Beside the dependency on H-index value, the distribution factor of citations over publication is not taken into account. In the artificial examples for this index, and in the case of authors: A and B in Table 11, the index returns the same value for both authors despite the clear difference as they have the same age. In another issue, authors: C and D, the M-quotient indicates that author C has more influence than D which is an incorrect indication as it is clear in the example that the reality is different even though the author D is older than author C by one year. Only exceptional cases can compensate for the age difference. Moreover, the publication age can be an enhancing factor for the M-quotient value if it is used.

Table 11. M-quotient Artificial Examples

	Authors			
PaperID	A	B	C	D
1	4	30	10	400
2	4	17	10	150
3	3	12	10	133
4	0	1	10	90
5	0	1	10	88
6	0	1	10	22
7	0	1	10	11
8	0	1	10	11
9	0	0	10	10
10	0	0	10	10
Author_age	5	5	10	11
H-index	3	3	10	10
M-quotient	0.6	0.6	1	0.91

3.12 Q^2-index

Similar to HG-index, the Q2-index creates also a dependency on M-index in addition to the H-index. This aggregation may add advantages but it may also inherit weaknesses. As shown in Table 12, in the case of authors: A and B, the Q2-index indicates that author A has more influence than author B which is an incorrect impression, looking at the Table as the author B has more cited works than A. With respect to the sensitivity of the index, when the first publication of author C gains 10 more citations, then the Q2-index is not affected. However, one citation added to the forth publication make the value different. This is due to the usage of median function.

Table 12. Q2-index Artificial Examples

	Authors				
PaperID	A	B	C	C'	C"
1	10	77	10	20	10
2	10	16	9	9	9
3	7	5	9	9	9
4	7	5	8	8	9
5	5	5	7	7	7
6	3	5	7	7	7
7	3	5	6	6	6
8	0	2	5	5	5
9	0	1	5	5	5
10	0	1	1	1	1
H-index	5	5	6	6	6
M-index	7	5	8.5	8.5	9
q2-index	5.92	5.00	7.14	7.141	7.348

3.13 K-index

The rest of publications that are not part of the H-core are significant for the K-index. For example, the author A in Table 13 shows an example of how to calculate the K-index based on the equation: K-index= (C/P)/(C(H-Tail)/C(H-core)). Unfortunately, many problems can be seen in the results of K-index besides its dependency on H-index value.

Table 13. K-index Artificial Example

	Authors			
PaperID	A	B	C	C'
1	10	5	70	70
2	10	4	22	22
3	8	4	40	40
4	7	0	33	33
5	5	0	12	12
6	4	0	12	12
7	3	0	9	9
8	0	0	2	2
9	0	0	1	1
10	0	0	0	1
C	47	13	201	201
P	10	10	10	10
C(T)	7	0	3	4
C(H)	40	13	198	198
K-index	26.857	#DIV/0!	1326.6	999.9

In some cases and due to mathematical problems, the K-index may cause a division by zero errors (e.g. author B) as the contents of h-tail = 0. In another issue, the case of author C in Table 13 seems to be odd when the 10^{th} publication gains its first citation. The value of K-index was decreased by 326.7.

3.14 H_W-index

Using the behavior of H and G indices, the H_W-index was proposed to enhance the H-index and to give more attention to the highly cited publications. Table 14 below shows some

artificial examples to demonstrate H_W-index issues. As can be shown from the examples, some of H-core contents were ignored in the calculation of HW-index. The high value of H-index may cause the H_W-index to give opposite impressions as in the cases of Authors: A and B. The author A has publications with a high number of citations more than author B. Nonetheless, the H_W-index results made opposite indications comparing those two authors. This index is based on G-index behavior, where the cumulative summation of citations is used in the calculation as well as the "Big-hit" problem. Such cases may occur in many cases and may then mislead the index. Like any index which does not take the time in its calculations, the view may be different if the publications or if the author's age was provided and included in the formula.

Table 14. HW-index Artificial Examples

	Authors	
PaperID	**Author A**	**Author B**
1	200	200
2	55	44
3	40	26
4	33	5
5	25	5
6	25	4
7	5	3
8	5	0
9	4	0
10	1	0
H-index=	**6**	**5**
Sum H-core	**378**	**280**
HW-index	**15**	**15.621**

3.15 The J-index

In addition to its dependency on H-index, the J-index has many weaknesses related to its calculation. Table 15 shows some artificial examples to demonstrate issues with J-index. The major issue in this index is its sensitivity as it can be seen from the cases of authors: A and B in Table 15. Although, the publications of author B exceeds the publications of author A in 4386 citations totally and 4365 in the H-core, the J-index value difference between both authors is only 1.55 index points. Another serious problem related to sensitivity is also shown using authors: C and D. Author D has 481 citations more than author C, in total, 415 of them are in H-core. Nonetheless, the J-index value for both is the same. Moreover, if the first paper of author D gains 5 more citations then the J-index will be 15.547. This means it will be increased by 0.0805 index points. As shown, the J-index has a different behavior with the increment of citations. For example, J-index is increased with +5 citations in one case, while it stayed the same with +415 citations in another case.

Table 15. J-index Artificial Examples

	Authors			
PaperID	A	B	C	D
1	1000	1300	360	695
2	900	1200	330	345
3	800	1100	100	130
4	200	1000	90	120
5	100	950	50	55
6	50	700	27	27
7	50	550	27	27
8	40	310	27	27
9	30	290	20	20
10	25	110	20	20
11	20	50	20	20
12	15	30	19	19
13	15	20	19	19
14	15	15	18	18
15	5	11	10	14
16	5	10	9	14
17	4	10	9	14
18	1	5	9	13
19	X	X	8	13
20	X	X	8	13
21	X	X	7	12
22	X	X	6	11
23	X	X	5	10
24	X	X	3	10
25	X	X	3	10
26	X	X	1	10
H-index	**14**	**14**	**14**	**14**
Total Cit.	**3275**	**7661**	**1205**	**1686**
Total H-core	**3260**	**7625**	**1127**	**1542**
Diff. in Total	**4386**		**481**	
Diff. in Core	**4365**		**415**	
J-index	**16.21**	**17.76**	**15.466**	**15.466**
Diff. in j-index	**1.55**		**0**	

4. Summary and Conclusion

An extensive survey is conducted in this paper for the majority of citation indices for evaluating the impact factors for research papers and authors. Using examples, we showed some limitations in those indices. The majority of those indices seem to be following and adapting H-index in focusing on the "H-Core" papers which are those papers for a particular author that get the highest number of citations. Two problems are discussed with this issue. The first issue is that such focus on the most cited papers causes those indices to include the large possible number of new publications for the author as they will be ignored relative to the most cited papers. The second issue is that the majority of those indices are insensitive to the increase of the number of citations for those most cited papers and the citation index become rigid and stable in a way that makes it hard for the index value to be changed even

with the increase of the citations. In addition, we showed that all citation indices ignore important factors related to the paper and the author. This includes for example, the paper age, author age, co-authors' factors, etc.

References

[1] Garfield E., "Citation Indexes for Science; A New Dimension in Documentation through Association of Ideas", Science, vol. 122(3159), **(1955)**, pp. 108–111.

[2] Hirsh, J. E.,"An index to quantify an individual's scientific research output". Proceedings of the National Academy of Science of the United States of America, vol. 102, no. 46, **(2005)**, pp. 16569-16572.

[3] Kelly, C. D., and Jennions, M. D., "The H-index and career assessment by numbers. Trends in Ecology and Evolution", vol. 21, no. 4, **(2006)**, pp. 167–170.

[4] Egghe, L., "Theory and practice of the G-index". Scientometrics, vol. 69, no. 1, **(2006)**, pp. 131–152.

[5] Kosmulski M., "A new HirscH-type index saves time and works equally well as the original H-index", ISSI Newsletter, Vol. 2, no. 3, **(2006)**, pp. 4-6.

[6] Jin, B. H., "H-index: An evaluation indicator proposed by scientist", Science Focus, vol. 1, no. 1, **(2006)**, pp. 8-9.

[7] Bornmann L., Mutz R. and Daniel H-D., "Are There Better Indices for Evaluation Purposes than the H-index? A comparison of Nine Different Variants of the h Index Using Data from Biomedicine", Journal of the American Society for Information Science and technology, vol. 59, no. 5, **(2008)**, pp. 830-837.

[8] Zhang C. T., "The e-index, Complementing the H-index for excess citations", PLoS One, http://www.plosone.org, accessed on **(2011)** October 25.

[9] Alonso S., Cabrerizo F. J., Herrera-Viedma E. and Herrera F., "HG-index: a new index to characterize the scientific output of researchers based on the H- and G-indices", Scientometrics, vol. 82, no. 2, **(2010)**, pp. 391-400.

[10] Cabrerizo F. J., Alonso S., Herrera-Viedma E. and Herrera F., "Journal of Informetrics", vol. 4, no. 1, **(2010)**, pp. 23-28.

[11] Bornmann L. and Marx W., "The h index as a research performance indicator", European Science Editing, vol. 37, no. 3, **(2011)**, pp. 77-80.

[12] Costas R. and Bordons M., "The H-index: Advantages, limitations and its relation with other bibliometric indicators at the micro level", Journal of Informetrics, vol. 1, no. 3, **(2007)**, pp. 193-203.

[13] Sidiropoulos A., Katsapro D. and Manolopoulos Y., "Generalized Hirsch H-index for disclosing latent facts in citation networks", Scientometrics, vol. 72, no. 2, **(2007)**, pp. 253-280.

[14] Ye F. Y. and Rousseau R., "Probing the H-core: an investigation of the tail-core ratio for rank distributions", Scientometrics, **(2009)**.

[15] Egghe L. and Rousseau R., "An H-index weighted by citation impact", Information processing and management, vol. 44, no. 2, **(2008)**, pp. 770-780.

[16] Prathap G., "Is there a place for a mock index?", Scientometrics, vol. 84, no. 1, **(2010)**, pp. 153-165.

[17] Anderson T. R., Hankin R. K. S. and Killworth P. D., "Beyond the Durfee square: Enhancing the H-index to score total publication output", Scientometrics, vol. 76, no. 3, **(2008)**, pp. 577-588.

[18] Wu Q., "The w-Index: A Measure to Assess Scientific Impact by Focusing on Widely Cited Papers", Journal of the American Society for Information Science and Technology, vol. 61, no. 3, **(2010)**, pp. 609-614.

[19] Bornmann L. and Mutz R., "The h index research output measurement: Two approaches to enhance its accuracy", Journal of Informetrics, vol. 4, no. 3, **(2010)**, pp. 407-414.

[20] Menzies, T.;Chen, Z.; Hihn,J. and Lum, K. (2006). Selecting Best Practices for Effort Estimation, IEEE Trans. Softw. Eng., vol. 32, 11, **(2006)** November, pp. 883-895.

[21] Peter Vinkler, The πv-index: a new indicator to characterize the impact of journals, Scientometrics Journal, vol. 82, no. 3, **(2008)**, pp. 461-475.

[22] Chun-Yang Yin, Do impact factor, h-index and EigenfactorTM of chemical engineering journals correlate well with each other and indicate the journals' influence and prestige? Current Science, vol. 100, no. 5, **(2011)** March.

[23] Ludo Waltman and Nees Jan van Eck, The inconsistency of the h-index, Journal of the American Society for Information Science and Technology, **(2011)**, In press.

[24] Quentin Burrell, On Hirsch's h, Egghe's g and Kosmulski's h(2), Scientometrics, vol. 79, no. 1, **(2009)**, pp. 79–91.

[25] Jin, B., Liang, L., Rousseau, R., & Egghe, L., The R- and ARindices: Complementing the h-index, Chinese Science Bulletin, vol. 52(6), **(2007)**, pp. 855–863.

Authors

Majdi Maabreh

Majdi Ahmad Maabreh is a master student in the department of Computer Information Systems at Yarmouk University in Jordan. He received his bachelor's degree in computer science from Yarmouk University in Jordan in July 2004. Since 2004, he joined the team of programming and development of database systems at the Hashemite University. The most topics interest includes Search Engines Technology, Data Mining, Information Retrieval as well as Databases Technology.

Izzat Alsmadi

Izzat Mahmoud Alsmadi is an assistant professor in the department of computer information systems at Yarmouk University in Jordan. He obtained his Ph.D degree in software engineering from NDSU (USA), his second master in software engineering from NDSU (USA) and his first master in CIS from University of Phoenix (USA). He had B.sc degree in telecommunication engineering from Mutah University in Jordan. He has several published books, journals and conference articles largely in software engineering and information retrieval fields.