**A CENTURY OF WEB HANDLING
LITERATURE**

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ABSTRACT

This paper is a review of some 3,500 published works in the areas of web handling, winding, converting and related subjects. These individual works include articles, books, columns, conference papers, instruction manuals, theses, course notes and other material spanning the better part of a century. There are hundreds of authors that have contributed to this vast body of industrial art and science. These authors represent scores of companies, independent consultants, universities, trade organizations and trade publishers. The individual works were found by a combination of professional and public database searches as well as direct inspection of collections at libraries, attendance at conferences, magazine subscriptions, websites and other sources. These original works were then inspected for the bibliographies contained therein and added when new and relevant items were found. All web related works were entered into a flat database of a dozen fields that extended beyond the obvious (author, title, publication) to include such information as author's employer, copyright holder, rating and other fields. The search and database construction took place over the course of a quarter century.

Analysis of this database within this paper includes a study of publication counts by author, subject, type and source. While the great majority of authors have only a single or a few web handling publications, some of those are uniquely valuable as they may be the only treatment of a particular topic. A handful of authors have more than one-quarter century of steady publication. Even so, the most prolific author still only accounts for less than 10% of the total. The organizations that account for the majority of the web related publications include TAPPI, Paper Film Foil Converter Magazine, the Converting Magazine, AIMCAL and, of course, the Web Handling Research Center. The publication count ranking nearly matches the age of the major organizations, possibly suggesting a steady publication rate. Unfortunately, the overall publication rate seems to show the

common life-cycle pattern of development, introduction, growth, maturity and decline. If TAPPI publications are not considered, because the paper industry has been in a decade plus long decline, the remaining publication rate seems to be holding since its peak in the mid 1990's. A prospective of near future publication is also given.

THE ORIGINS OF THE TERM 'WEB-HANDLING'

The origins of the term 'web handling' as we currently understand it may well precede the formation of the WHRC (Web Handling Research Center) at Oklahoma State in the mid 1980's. While the specific time and source of 'web-handling' may never be known, it is not important here. What is germane is that the usage was clearly quite confined until that time. Thus, a literature search, no matter how skilled and well meaning, will yield almost no older results using that phrase. Yet, clearly web-handling is far older than this. Textile looms are thousands of years old and are clearly web machines and resemble modern looms in most key ways. For example, tension control of the warp strands is just as important now as ever for product quality else you risk one mechanism to baggy webs. Another example is paper that is still made on a fourdrinier, an endless belt, whose invention was conceived in the late 1700's and whose commercialization essentially replaced previous batch paper making methods well before the mid 1800's. Guiding, tension control were required arts *and* sciences not only in the forming section, but downstream.

Much of the early science was confined to the engineering departments of large machine builders such as Beloit Corporation [1]. The origin of this particular company was the Merrill & Houston Iron Works, a foundry built in 1858 to serve paper mills and other industries. It had built 104 paper machines prior to 1885 when the company had financial difficulties and was reorganized and renamed the Beloit Iron Works. An early public demonstration of its products was the display of a fully assembled newsprint paper machine at the 1893 Columbian World's Fair in Chicago. After the show the paper machine was dismantled and shipped to its owner Nekoosa (Wisconsin). Since then the engineering prowess of Beloit Corporation had become legendary even well outside of the paper industry. For example, it performed high-cycle (over 10^6) fatigue analysis on various metallurgies to ensure roller journal safety even before jet turbine manufacturers. Also, it had written its own CAD (computer aided drafting) and later CAM (computer aided manufacturing) programs because the commercial products of the time were entirely inadequate. These home-grown codes were good enough that at least one automotive company offered to buy it. FEM (finite element modeling) and FFT (Fast Fourier transform) capabilities were found in nearly every engineering department. Sadly, due to a number of factors, Beloit Corporation announced Chapter 11 on June 7, 1999, effectively ending a nearly century-and-a-half of web handling engineering.

A more 'recent' example of very web handling specific language comes from an instruction manual for a Case steam powered stationary threshing machine [2]. While the wording may be different than we are accustomed to, the science, as the title proclaims, is clearly web handling. The first excerpted passage, from page 136, describes how to initially align the steam engine and threshing machine pulleys and then elsewhere how to compensate for a developing afternoon wind on the long spans.

If trouble is experienced in getting the engine in line, this method may be used to correct the alignment until practice enables the operator to set the engine so that the belt will run in the center of both crowned pulleys.

A second passage, from page 76, describes how the belt lace (splice in web handling terminology) must be square and even else the belt will not be evenly taut (bagginess in web handling terminology) and will run off to one side.

Care must be taken to keep lacing as near the same tension throughout the width as possible, so one edge will not be tighter than the other, which will cause the belt to be crooked and not run true.

Finally, I offer a final few justifications for an ancient web-handling heritage. First we consider the longest continuously running magazine carrying regular web handling content [3]. *Envelope Industry* was first published in March 1927. After several name changes it became the *Paper, Film, Foil Converter*. This trade magazine has one of the largest monthly subscriptions of any other journal in the web handling industries. The monthly magazine carried regular web handling content, such as Tim Walker's *Web Lines* first penned in 2002. However, he was preceded by an even more prolific author, Herbert Weiss, who in addition to numerous articles published no less than five books. Articles that are clearly hard web-handling science, as evidenced by equations and supporting empirical data, began to proliferate in the 1950's. Much of this was in the areas of winding and material property measurement. A notable fraction of this early hard science was published in the Tappi Journal. TAPPI (previously an acronym for the Technical Association of the Pulp and Paper Industry) was formed in 1915. Since then TAPPI has grown into the world's largest professional association serving the pulp/paper, nonwovens, converting and packaging industries.

WHAT IS 'WEB HANDLING'?

While we owe an enormous debt of gratitude to the WHRC in helping to make the phrase 'web-handling' *nearly* a household word, this term is even now far from universal. Thus, for example, you could have a subsequent landmark paper in a refereed journal [4] or even an entire book [5] published on a major topic such as winding and not find a single usage of 'web-handling' anywhere in the text. This limitation is just the first of many enormous practical and tactical difficulties in assembling a web-handling library. So what does web-handling include? It is a loose collection of arts and sciences that can be used to improve the runnability of web manufacturing and converting. By runnability we mean reducing certain types of waste and delay. Though wording might vary, the subsets of web-handling generally fall into the areas as given in Table 1. Note that those subjects in the 'major' column are the traditional areas where much of the work of the WHRC has focused. However, no less important are areas that have received less attention there, but much more so elsewhere as given in the second column. For some industries such as paper, moisture [6] and web breaks [7] and cores are so vital that no less than a hundred refereed research papers have been published on each. Clearly these subjects are web handling related because they involve virtually all of the constituents of 'traditional' web-handling areas. They also directly affect or are affected by the stresses and strains in web handling. A more generic example is the design of web machines that clearly must be well grounded in web handling principles and includes all of the more traditional web handling-areas [8, 9].

Major	Supporting
Air Entrainment (roller and winding)	Design of Web Machines
Guiding (path control)	Design For (Web) Manufacturability
Nips	Measurement – lab/offline measurements
Rollers	Measurement – online sensors
Tension Control (also drives)	Moisture and Temperature Effects
Winding (including cores)	Runnability (web breaks etc)
Wrinkling	

Table 1 – Important Web Handling Topics

PRACTICAL DIFFICULTIES SEARCHING WEB-HANDLING TERMS

From the last section we clearly saw the difficulties that result because the phrase 'web-handling' was a recent coinage and because even to this day a good fraction of the literature does not use it. So rather than deal with web-handling as a search term, why use each of the major areas in turn? In other words, why not search separately on words such as tension, winding and wrinkling and then assemble them at the end to make a master literature list? Certainly this can and is done. However, tremendous language issues result from this approach [10]. For example, *tension* has many meanings well outside of web-handling including such science items as synonyms for voltage and a common 'cause' of headaches. It is easy to see that even if the usages are science related, by no means a given in searches, most are totally unrelated to web-handling. *Winding* is even more problematic because you would have to search on wind + winder + winding. (Similar problems are seen when doing 'coating' or 'printing') These root word variations add to the difficulties. Thus if you search using the root word *wind* you will get hits as diverse as meteorology, wind power or windings on electric motors that swamp the relevant. If you search on *wrinkles*, especially using popular search engines, the first couple of pages will largely be for Botox® treatments. Using subscription-based reference library searches will help some, but the results are still largely irrelevant even using the most skilled search methods. Tightening the searches to reduce the irrelevant often also misses more of the relevant.

METHODOLOGY TO ASSEMBLING A WEB-HANDLING LIBRARY

Several distinct search methods are needed to assemble a reasonably complete web-handling library because any single method will be quite incomplete. Even so, the attitude of a 'collector' will be overarching. Just like any avid collector of coins or stamps, for example, one would eventually want to have one of everything within the domain of the collection. The artistic merit or circulation does not determine whether an item is desirable, only the price that must be paid. The brute force method to find things is to go to a collection or list that is complete. For example, I went to the Oklahoma State University Edmund Low Library because they happened to have had a complete set of Tappi Journals going back to the 1950's. I literally went through the table of contents of each and every issue looking for web handling and related content. Similarly, there are lists of the hundreds of TAPPI Finishing and Converting Conference papers during its two-decade history. (Note: this and several other divisions disbanded in 2001 during a severe economic slump of the paper industry). Another productive method for finding web-handling material included subscribing to magazines and journals. Finally, regular

attendance at conferences where web-related papers are given yields a treasure trove of titles, papers, bibliographies and face time with authors and like-minded attendees.

More targeted methods to finding material would be similar to what a reference librarian or researcher might use; commercial search services on specific terms. Web breaks (runnability) and moisture where filled out thus. Finally, other methods such as obtaining theses or being on thesis committees allowed me to borrow the results of the search efforts of others. Of course, each and every bibliography was inspected for new material and entered when appropriate. The only method not used was to consult a citation index because it was not found to add much to the existing set obtained from other methods. Approximately 3,500 articles, books, columns, instruction manuals, papers, theses and similar matter have been entered as of this date.

Data fields for the information, listed in Table 2, were more complete than what is found in most catalogs.

Expected Fields	**Additional Fields**
Author (full name)	Quality / Usefulness Ranking (my estimate)
Title	Internet Link (when available)
Reference (full)	Copyright Holder(s)
Publication Date	Author Affiliation (s)
# Pages	Publication Type (book, column, etc)
Keywords	
Abstract (very abbreviated)	

Table 2 – Data Fields of the Web Handling Library

Keywording presented both challenge and opportunity. Challenge, because many items are not keyworded in either other databases or in the original articles. Also, when they are keyworded, the results are very inconsistent between authors and journals. Thus, each item was re-keyed by a single professional, me, who is familiar with the area and might (hopefully) be expected to be more consistent. Another challenge was encountered with the abstract data field because of limitations of the current database software, Microsoft Access. (Earlier incarnations of the library were stored in Borland's Reflex.) The database is enormous already and would be slowed even further unless the default of 256 characters field size was accepted for the abstract field. Also, some of the fields such as abstract, internet link, affiliation and ranking have been added since the database was first constructed in 1983 so that not all of those data boxes have been updated. Finally, even when traditional fields are used, they are usually more complete than is traditional. For example, Author includes first names, when known, and Reference includes date as well as the traditional Volume and Number.

ANALYSIS OF THE DATA

The first cut at data analysis is to see what types of documentation are found in the public domain as given in Table 3.

Document Type	Number Of
Magazine	1577
Conference	592
Thesis	62
Report	61
Book	57
Shortcourse	56
Standard	24
Course Notes	11
Unknown or not keyworded	1006

Table 3 – Number of Documents of Each Type

It should not be surprising to find that the literature is dominated with periodicals and conferences because they publish regularly. Perhaps the only surprises might be the large number of books and the low number of standards (most probably an artifact of data gathering limitations). Similarly, we might look at the distribution of copyright holders as given in Table 4.

Document Type	Number Of	Age of Org. (Yrs)
TAPPI	974	95
PFFC Magazine	341	85
WHRC	320	26
Converting Magazine	308	27
AIMCAL	215	40
Unknown or not keyed	1288	

Table 4 – Copyright Owners and Age of Organization

With the exception of AIMCAL, the ranking of copyright owners corresponds exactly to age of the organization. Not surprisingly, the older the organization, the more they have published. However, even AIMCAL might not be an exception because conferences earlier than about 1995 clearly contained some web handling content but were not entered due to data gathering limitations. Thus, all of the above organizations seemed to have produced at a similar steady rate for most of their lifetimes. This count of articles is by no means an attempt to judge quality or contribution to industry, it is just simply an observation. Another useful way to look at the data is to see what subjects are popular as seen in Table 5.

Subject Keyword	Number Of
Winding	810
Tension	347
Slitting	198
Nip	162
Coating	146
Wrinkling	142
Cores	122
Guiding	92
Spreading	89

Table 5 – Popularity Ranking of Subjects

Without surprise, winding is clearly the most popular subject. Also note that the popularity of other subjects is broadly similar to what is observed at the WHRC with a few exceptions. The first is that wrinkling and spreading, while still popular, have enjoyed more attention there than elsewhere. Also, elsewhere we find relatively more interest in processes such as slitting and coating and that should also be no surprise because those have been mostly ignored due to the original scope guidance provided by the WHRC's board. Also note that very common keywords such as 'measurement' or 'testing' have not been included in the above table because these are included in sizable fraction of documents even if measurement were not the primary focus. Finally, we note publication frequency by author as seen in Table 6

Author	Number Of Documents
Dr. Roisum	312
Tim Walker	120
Dr. Good	61
David Pfeiffer	39
Herbert Weiss *	22
Other or unknown	2892

Table 6 – Frequency by Author

Again there are no real surprises that authors who write in periodicals have a greater publication count. *Note that Herbert Weiss published a lot more than is shown here, but his columns are much older and harder to find and thus are underrepresented. One extremely positive note is that even the most published author has less than 10% of the publications. Web handling publication is truly egalitarian with substantial contributions made by countless scientists and practitioners.

Again, of course, simple counts of documents or pages do not necessarily reflect quality or overall contribution. Perhaps the only attempt at grading research contribution of either individuals or departments that has any standing is the H-Index. It is based on a simple premise that the more an author's work is referenced by others, the more it must be worth as judged by their peers. Even so, the H-index has generated a firestorm of criticism. For example, older authors (especially the deceased) automatically will place better as well as do people who pad their own work with self-reference. The Google-gadget H-index calculator results are not shown here for web handling authors because only recent articles are found on Google are counted and thus is incomplete. Worse yet, the list of publications used for the calculation suffers from enormous name confusion,

especially for common names such as 'Good' and 'Reid'. Thus, even the most well-intentioned and respected ranking of the contribution of authors to science is irredeemably flawed unless one undertakes the tedious manual verification of every citation to make sure that it is valid.

TEMPORAL TRENDS IN PUBLICATION

One very important investigation was to see if the rate of publication has changed with time. As seen in Figure 1, the publication rate apparently changed enormously; by about an order of magnitude in our professional lifetime alone. Granted, early publications are probably underrepresented. Part of this is because older publications may be difficult to find because cataloguing (and later digitization) efforts tend to work backwards from the present and may not be complete or may have ended due to funding decisions. For example, seldom does the digitization of trade magazines extend back before the year 2000. Also, some early publications may well be lost forever as magazines go out of business and issues become scarce or obsolete. An example is the Converting Magazine website that went dark when the magazine was closed last year along with 23 other titles owned by Reed Business. While paper content is still available in some public libraries, website content has apparently been erased due to a lack of interest in the owners to bother with selling it to organizations who had made a bid on it. Even so, it is clear from the decades of the 80's and 90's when cataloguing is relatively complete that there was not so much 'web handling' activity then even under different names. Also of great concern is the precipitous fall-off of publication rate in recent years. Since its peak in the late 1990's, web-handling publication rates have plummeted an astounding 75%!

Products tend to have a life cycle pattern composed of four stages resulting in a bell-shaped quantity versus time plot, roughly resembling what we saw in the previous figure. The first stage is invention in engineering or introduction in marketing. Here rates are very low and only slowly increasing. The second stage is growth. As public awareness increases and economies of scale improve, the rate enjoys a positive first derivative. However, this growth is short-lived as the technology saturates market needs so that growth peaks in the maturity stage. The final stage is decline as one technology is subsumed or made obsolete by another. The question here is "whether web-handling is saturated or even in decline as hinted at by the overall publication rate?"

To tease out this possibility, we need to consider a trend that we noted earlier; that is that TAPPI alone held about one third of the publications. We know that both the paper industry in general and TAPPI in specific have suffered enormous decline since the mid 1990's due to economic downturn that is somewhat specific to paper. (Note this study does not include the recent 'Great Recession'). To compensate for this known trend in paper, we can subtract out TAPPI publications. Fortunately, as shown in Figure 2, the rate of non-paper industry publications seems to <u>not</u> show large decline. Further evidence can be seen from instruction. There are more web handling instructors and more shortcourse hosts now than ever before. About 5,000 students have been trained in public courses offered by WHRC, AIMCAL and Seminars for Engineers. Even more students have been trained in plant by consultants such as Roisum and Walker.

THE NEAR FUTURE OF WEB HANDLING

Predicting the future of a technology is notoriously difficult. However, I will venture a few educated guesses on trends based on what we have seen in the recent past. First,

publications will probably decline further as we saturate the needs of our customers. There is no reason to expect otherwise. Also, it is possible that the nature of future 'publications' will morph from static refereed papers to dynamic e-publications such as blogs, websites, wikis and so on. Much more important, however, is that the barrier to publication will become nearly insurmountable if it is not already so. As we showed earlier, the decline of active industry participation in attendance much less presentation started long ago and has slowed to a mere trickle. Part of this is due to lean engineering staffing that leaves little time for reflection, much less writing. Another trend is more activism by legal departments who would prefer that little be published else the company be exposed to the possible loss of trade secrets and perhaps even liability. Thus, what little we can expect in the near future must come solely from academia and consultants. While it is difficult to predict the level of graduate student and professor publication rates, it is much more so for consultants. No new web-*handling* consultants have emerged for almost two decades and since then two are retired or nearly so. However, this trend may be unique to web handling because a tiny handful of successful consultants have emerged in web manufacturing and converting areas.

Even the wildly successful training programs in web handling and related areas are probably not immune to life-cycle trends. Much of the training is, in my opinion, because machine builders have not always done their homework. This means, for example, that we have to teach rollers and spreading to plant personnel. This would be analogous to teaching tires and engines to an automobile driver; little would needed if designs were robust and reliability were high. If web machine design transitions from a mix of art and science to more of a science, the need to teach in the plants should also decline. However, this transition will be slowed due to the same factors; engineers at machine builders are also spread quite thin. Perhaps this is why we see so few builders attending or hosting web handling training.

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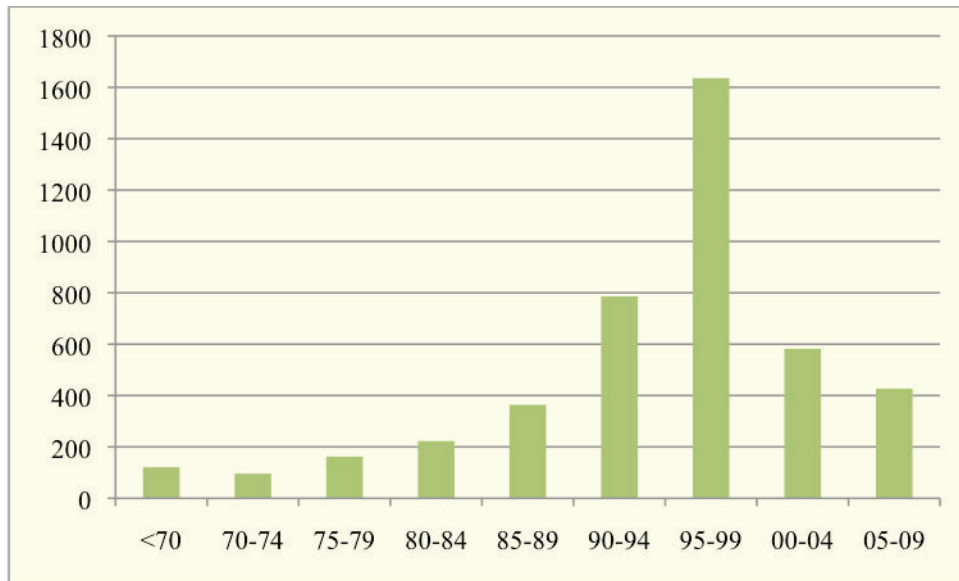
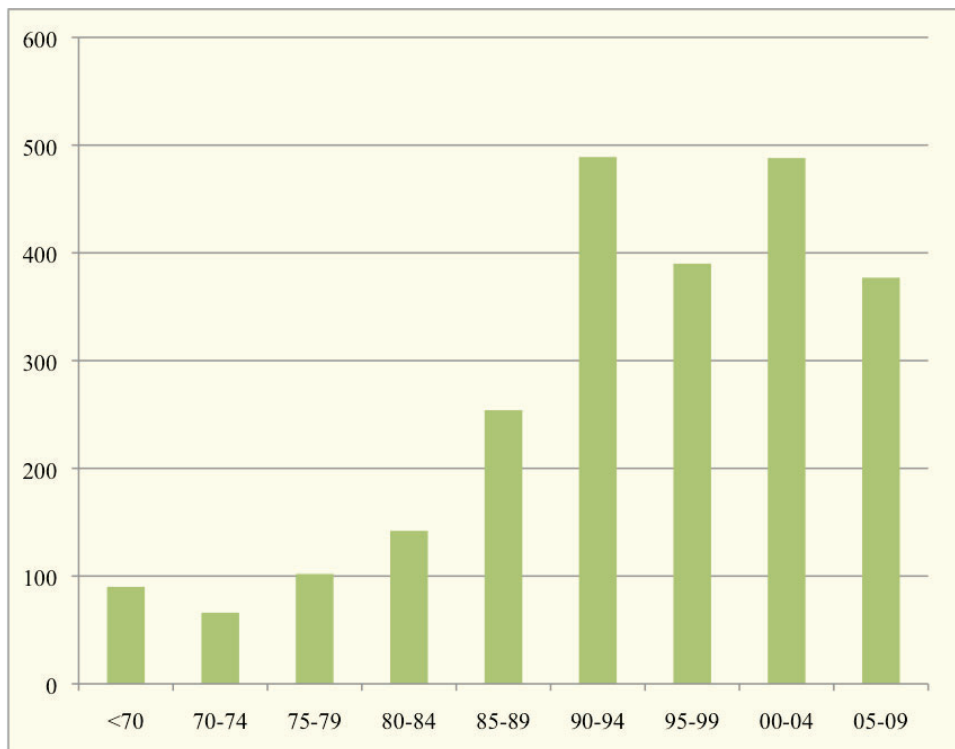Figure 1 – Web Handling Publication Rates Through Time

Figure 2 – Non-Tappi Publication Rates

Name & Affiliation	Question
Bob Lucas, Winder Science	I have many technical papers that I have collected. The practical question is if I were to feed that information to you so you could supplement your library, how would I organize it?

Name & Affiliation	Answer
Dave Roisum, Finishing Technologies, Inc.	You don't need to do any organizing, just mail me the box and I'll take care of it. If anyone finds any errors or omissions, just let me know. My attempt is to collect as much information as possible. Foreign language is a big problem. If I don't have an English translation of the title, it's pretty much worthless, because then we don't know how to keyword it.

Name & Affiliation	Question
Bob Lucas, Winder Science	I have another question. Your database is primarily English based. I am sure there are databases in Germany, Finland Japan and other countries that represent efforts that you don't know about.

Name & Affiliation	Answer
Dave Roisum, Finishing Technologies, Inc.	I'm sure of it. I see several foreign representatives here, but unless it is translated, it is not useful. The title must be translated in order to get a keyword.

Name & Affiliation	Comment
Mark Weaver, Rockwell Automation	I worked in the technical publishing field for a while. One very useful tool is Google Scholar. How many people use Google Scholar? I just entered a search on Google Scholar using the terms web handling, wrinkling and the third article that came up was "The Mechanics of Wrinkling," by David Roisum. This is a useful tool if you know how to access it. By the way, the first listing was a paper by Dr. Pagilla. It cited over a million citations. It is a rough sorting tool, but it certainly came up with some good citations right away.

Name & Affiliation	Question
Günther Brandenburg, Technische Universität München	Our discussions have shown that papers written in German are not known. Do you see any possibility in translating them into English? I would like to send you some of them, but I cannot translate them myself.

Name & Affiliation	Answer
Neal Michal, Kimberly Clark	Let's hold that discussion for the Discussion session later.