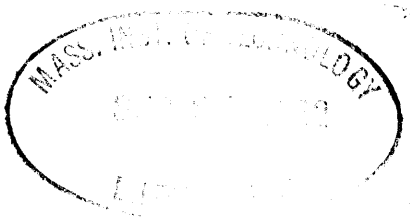

A STUDY OF BRAILLE CODE REVISIONS

by

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Abstract

A STUDY OF BRAILLE CODE REVISIONS

Gerald F. Staack

Submitted to the Department of Mechanical Engineering on August 31, 1962 in partial fulfillment of the requirement for the degree of Master of Science in Mechanical Engineering.

This thesis is an analytical study of Grade II braille for the purpose of determining what revisions are necessary to make it possible to translate from regular printed material to braille. At the present time this problem is complicated by both the 189 contractions which are used in braille and the requirements that many of these contractions not be allowed to overlap syllables. A complete description of the braille system is given, as well as the history of its development and the arguments concerning its adoption in this country.

Three criteria are developed for the evaluation of braille contractions. These are:

1. Their ability to reduce the bulk of material saved as determined by their frequenct of occurrence and the number of characters saved each time they are used.
2. Their effect on the readability of braille as evaluated by previous studies.
3. Their ability to be translated mechanically without consideration of pronunciation or syllabication.

The contractions are divided into groups on the basis of their braille form and the rules governing their use, The contractions within each category are then evaluated with respect to the above three points. Specific recommendations are made concerning the omission of infrequent current contractions, the adoption of new contractions, and changing the rules restricting the use of some contractions. The overall efficiency of the braille contraction systems as a means of saving characters is evaluated in terms of the mathematical theory of communication.

Some of the recommended changes were tested on a sample of blind people. Both the results of the reading test and the comments of the subjects strongly indicate that the recommended changes could be adopted with little problem for the average blind person and with desirable long range effects.

A computer program has been written to count the frequency of contractions in various texts and to record the words in which they occur. This program should serve as a useful tool in future evaluation of present contractions, and also proposed changes of contractions and existing braille rules.

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A STUDY OF BRAILLE CODE REVISIONS

INTRODUCTION

Braille books and magazines are used by about 30,000 blind people in the United States.[22][a] In addition, more than 12,000 blind children are being educated at special schools in our country today.[27] Although there are several thousand volunteer braillists and several braille publishers in the country, they still are not able to meet the needs of these people. Furthermore, there are over 300,000[21] blind people in this country, most of whom have not learned braille. This is due, at least partly, to a lack of sufficient material available to make this learning of braille worthwhile.[21] A solution to the acute problem of providing more braille literature is to utilize the efforts of modern computers and high speed machines.

The difficulties of producing braille are twofold. In the first place, standard braille is not a letter for letter transliteration from printed English. Instead, standard braille contains 189 whole word and part word contractions, as well as additional composition signs. This means that an actual translation process is necessary in embossing

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(a) Numbers correspond to bibliography at the end of the thesis.

braille. Secondly, embossing raised dots in heavy weight paper is considerably more difficult than surface printing with ink, whether one copy or a thousand is required. The training of a braillist takes from approximately three weeks up to nearly two years, depending on the type of equipment the person is learning to operate. Even with a qualified braillist, embossing is a slow and painstaking process.

Recently, there have been developments through research which are designed to remove most of the physical labor now required in embossing. For example, the prototype model of an electric brailler is being assembled at M.I.T.[18] This device will automatically emboss braille when given a coded electrical imput signal generated by a punch tape reader or a mechanical translator. Where Grade I braille is acceptable, M.I.T. is also developing a standard electric typewriter with an encoder attachment.

Computers already have been programmed to translate from English into standard braille.[26] However, there is a serious drawback since the rules for usage of the braille contractions are based in part on the syllabication and pronunciation of a given word. Our language, therefore, requires that a dictionary be included in the computer memory to ensure that all words are translated correctly. Although it is beyond the scope of present computers to contain complete dictionaries, it is possible for partial dictionaries to be

programmed in order to suit the specialized vocabularies of particular books or authors. Nevertheless, the high cost of computer operation makes their use marginal for large lot braille printing, and completely impractical for small and intermediate lots at the present time.

In order to overcome this translation problem and to increase the volume of braille material available, it was suggested that a study of possible revisions in the braille code and its accompanying rules be made, with the intent of adapting the rules to simpler means of machine translation. Hopefully, these same rule changes will make the task of translation easier for braillists to learn and to apply. Thus, the value of braille would be further increased, since the difficulty of obtaining correctly embossed material would be reduced.

In undertaking any such program, however, it is soon realized that the problems of the blind reader deserve study and consideration as well as difficulties encountered by the human or machine translator. Otherwise, changes might be suggested which would make braille unreadable, or at least considerably more difficult to read. Such changes would be of dubious value since the total usefulness of the braille material available would not be increased.

Therefore, the purpose of this research is to make an examination of current braille rules, their derivation and

and their value, and then to recommend changes and methods for further study so that the usefulness of braille may be enhanced. Ideally, the effective use of modern technological development will contribute to both easier and faster reading of braille by the blind and to the increased range and availability of braille materials.

THE PRESENT FORM OF BRAILLE

Braille is composed of a series of cells, each of which has dots at any of six positions. For reference, the six positions are numbered in the following manner:

1 • • 4
2 • • 5
3 • • 6

The number of different characters available from this cell is 2^6 or 64, counting the space which contains no dots. Twenty-six of these characters are assigned to the letters of the alphabet. Punctuation marks and special braille composition signs, such as the capital sign, the number sign, the italic sign and others, are assigned additional characters. These signs are used to indicate things in braille which are shown by different type forms in regular ink-print. The numbers in braille use the same characters as the first ten letters of the alphabet and are distinguished by the use of the number sign.

Only Grade I braille could be formed from the above signs; this form is nearly, although not exactly, a letter for letter transliteration of ink-print. On the other hand, Standard English braille, which is also known as Grade II braille, includes 189 contractions of various types. Twenty-three words have alphabetic contractions, i.e. when a letter of the alphabet is found with spaces before and after or only touching

punctuation it represents a whole word. Examples of this form of contraction are: "b" representing "but," "c" representing "can," and "f" representing "from." Two words, "it" and "as" are represented by "x" and "z" respectively, whereas other alphabetic contractions are based on the first letter of the word.

Twenty-one part word letter combinations, such as: "ch," "st," "er," "ed," "com," "bb," and "cc," are contracted by assigning them some of the remaining braille characters. However, some of these part word contractions use the same braille characters as certain punctuation signs. Therefore, they require special rules limiting their placement in words or lines. An additional seven contractions for use as whole words only are formed from the above part word contractions in the same manner as the alphabetic contractions; e.g. "st" when standing alone as a word is read "still."

Thirteen more braille characters are used to form words. Six of these, "by," "into," "to," "was," "were," and "his," may be used only to represent whole words, but the other seven, "and," "for," "of," "the," "with," "in," and "be," may be used either as whole words or parts of words, such as in "candy" or "between."

Forty-nine whole and part word contractions are formed from the initial or final ink-print letter preceded by one of six braille characters. An example of this is "d" preceded

by dot 5, which is read "day," either as a whole word or as a part word, such as in Friday. The remaining seventy-six contractions are known as short-form words. These words are represented by two or more letters, similar to an abbreviated form. However, in many cases the particular word and short-form must be memorized by the reader in order to avoid confusion; for instance, "also," written "al" might, if not remembered, be confused with "almost," "already," or any of several other words. These short-form words may also be used as parts of words, provided that their meaning and pronunciation remain the same and their use does not result in an incorrect spelling.

There are also general rules concerning the use of contractions which prohibit their use when confusion might result due to changed pronunciations, contractions which overlap syllables, confusion with punctuation, difficulty in keeping on the proper braille line, or use in obscure or unusual words. A complete list of the 64 braille characters and their meaning, along with a list of the multi-cell contractions is given in Appendix A.

HISTORY OF BRAILLE

The history of tactile reading by the blind is considerably older than Braille. An account of how a blind Arab professor of the fourteenth century improvised a system of identifying his books and summarizing certain information by forming coils of tightly rolled fine paper into the shape of Arabic characters was given at an International Conference on Blind Welfare in Cairo.(10) Most early European systems of printing for the blind used Roman characters, which were usually raised but occasionally recessed. Many attempts, ranging as far back as the early sixteenth century, are reported of teaching the blind to read from movable type blocks and other raised letters. In 1676, a Padre Terzi devised a cipher code of dots embossed in squares and other figures. This was apparently one of the first attempts to use an arbitrary code instead of letters styled after those used by sighted people. The general lack of communication at that time, and perhaps the unsatisfactory nature of the various methods, seems to have encouraged more ingenuity than conformity , and many more systems were proposed. Although these systems were primarily working with raised Roman letters, a few other systems of an arbitrary nature seem to have appeared.

In 1829, the Royal Institute of Paris released the first official description of a system of printing for the blind,

which was developed by one of their blind students, Louis Braille. Previously, in 1819, two years after Braille's enrollment at the age of eight, a French artillery captain, Charles Berbier, submitted to the Royal Institute a system of writing with raised dots which he had developed to enable field soldiers to communicate in darkness. Berbier's system was based on speech sounds and used two vertical rows, with a row composed of one to six dots, to represent each sound. This method was accepted at the Royal Institute as a "supplementary method of teaching" in addition to the primary system of relief printed Roman letters. Braille learned Berbier's system and then set about to change it; apparently others also tried, but Braille's system is the only one of record. He reduced the character size to six dots instead of twelve, though still keeping the arrangement of two vertical rows. He then set out to combine the dot characters with the letters of the alphabet and other necessary symbols in some logical form. Eventually, he divided the sixty-three available symbols into seven lines, which are interesting as a mathematical exercise, but of little value even in learning the code, especially considering the newer word methods of reading instruction.*

During the following years Braille's system was merely one of many which had been introduced in Europe and the

*Those interested in the seven lines, their logic, and use in character assignments are referred to Appendix A.

United States. In 1853, E.C. Johnson[8] summarized and compared several of the systems of printing then available for the blind. Among the systems which he categorized as arbitrary were those of Dr. Moon and Louis Braille, even though many of Moon's characters are obvious derivations from Roman characters. Johnson's conclusion was that the raised Roman print of Alston or the American modification by Dr. Howe of the Perkins Institute were superior to any of the arbitrary systems because they kept a common link between the already somewhat isolated blind and those people with sight. He also cited the difficulty for sighted teachers to instruct the blind in reading an "arbitrary" system such as Moon's or Braille.

The adoption of Braille in England was primarily due to the work of a Dr. Armitage.[32] Although not totally blind, Armitage's sight was sufficiently impaired that he relied on his sense of touch for reading. He gathered around him a group of men who also were blind or nearly so, and likewise relied upon tactile reading. These men, who formed the Executive Committee of the British and Foreign Blind Association, studied the various styles of type then available. Most of the members read several systems of raised letters, and gathered views from other people after requiring a reading test before accepting their opinion regarding any system, since Dr. Armitage was strongly opposed to any idea

idea that tactile reading styles could be judged by the eye. The fact that the committee actively endorsed braille was instrumental in its eventual adoption in Great Britain.

In the United States, acceptance of Braille's idea of writing with dots gained general acceptance many years before his arrangement and coding became the standard. Objections were raised to the fact that because of his interest in mathematical organization Braille had, in some cases, assigned more easily recognized symbols to less frequently occuring letters. Therefore, a system known as American Braille was devised, using the same six dot cell but assigning characters with the fewest dots to the most frequently occuring letters. While a study of recognition of braille characters by Burklin[3] in Germany in 1917 indicated that those symbols with the least number of dots are not necessarily the most readable; it also indicated that a system such as American Braille might be slightly easier to read than Braille's original code. However, the chief advantage of American Braille was that it was easier to emboss by the dot by dot method in use at that time.

Another system, known as New York Point, also assigned the fewest dot characters to the most frequently occuring letters. This system differed from American Braille in that the cells were only two dots high and of variable length. Thus, not only were the number of dots reduced, but it also allowed a considerable saving in space.

While each of these systems had some apparent advantages, it was undesirable for all of them to exist simultaneously. In this situation, books had to be embossed in all three systems, a very expensive measure when one considers the cost of embossing, and that the blind educated in one system could not easily communicate with those educated in either of the other systems, for it is somewhat of a burden to learn one system, much less three. As a result, the Uniform Type Committee was formed to bring the various groups in the United States into agreement with each other. The Committee, in 1915, recommended that a system which combined the features of both American Braille and New York Point be adopted; this system the Committee referred to as "Standard Dot."(17)

The Commission on Uniform Type for the Blind was then formed to attempt the adoption of a uniform system in Great Britain and the United States, which would then be accepted throughout the English speaking world. The British were unwilling to make any extreme changes from their form of braille to Standard Dot, and consequently it was dropped in both countries.

Most systems of writing for the blind have used contractions in one degree or another to economize on space since all means of raised embossing tend to be bulky. One early system, that of Thomas Lucas of Bristol, England,(8) even went so far as to use each letter of the alphabet to stand for

two different words, as well as omitting most vowels in other words. In his system, the reader relied upon context to indicate which meaning was intended in a particular instance. While the United States had debated which type of embossing to use, the British had developed a contracted form of braille known as Grade II. In 1902 this system contained some sixty-eight contractions, many of which are still in use today. (See Appendix B.) Further development had added many more contractions by 1916, and in 1932, when Grade II was adopted in this country, it contained 185 contractions. However, in 1916 and the years immediately following, the Commission on Uniform Type for the Blind felt that Grade II braille as used in Great Britain was too difficult to read and that in some cases the contractions did not save sufficient space to warrant their continued use. The following are some of the changes they recommended in 1916:(17)

Grade I

"Fifth. That the use of the sign 2-6, as likely to be confused with the fraction-line sign, dots 2-5 be discontinued as the decimal point, and that the sign for full stop, dots 3-4-6, be used in its stead as conforming entirely to ordinary ink-print practice.

Sixth. That the dots 3-5-6 be used to indicate both the opening and the close of inverted comma or commas, and that this character be discontinued as the sign of interrogation.

Seventh. That dots 4-5-6 be used as the sign of interrogation and that this character be discontinued as the sign of the close of inverted comma or commas.

Note. Suggestions embodied in 6 and 7 reduce the number of separate signs to be learned by one, and though not in exact harmony, so far as the quotation marks are concerned, with letter-press usage, are in strict accord with the practice of typists and hence of practical value to the blind.

Grade II

Ninth. That the practice of doubling the letters b, c, d, f, and g, by placing them on the lower level be discontinued, on the ground that such practice usually violates the principle of correct syllabification, is otherwise of little economic value, introduces equivocation with the corresponding upper-level forms, and needlessly adds to the rules and regulations, a knowledge of which is necessary to a complete mastery of the system.

Tenth. That sequences of word signs without separation such as "ofthe," "andwith," "bymore," "tosome," be discontinued on the ground that the practice is not of harmony with letter-press usage and burdens the system with unnecessary rules and exceptions.

Twelfth. That the lower-level contractions for "to," dots 3-4-5, "into," dots 4-5 3-4-5, and "by," 4-5-6, be suppressed because of their equivocal nature and the artificial manner in which they must be used; and that dots 2-3-6 be used to stand for "to," dots 1-3-6 for "by," and dots 4-5, followed without separation by dots 2-3-6, for "into," and that these contractions be subject to the rules governing other word signs.

Thirteenth. That the lower-level contraction for "were," dots 3-4-5-6, be suppressed because of its equivocal nature, and that dots 1-2-3-4-6 be used in its stead as more suggestive of the word "were."

Fifteenth. That the following seventeen initial compound contractions, which show, respectively, less than two hundredths of one per cent in recurrence, and are represented by characters of comparatively low time and accuracy values, be wholly suppressed from the system, on the ground that they place a burden upon the memory far in excess of the advantage gained by their use:

> Christ, cannot, father, God, Jesus, Lord, mother, name, right, spirit, unto, word, would, young, character, those, whose."

The British apparently were unwilling to compromise sufficiently and the Commission finally recommended the adoption of a system known as Grade I and 1/2. This system contained forty-four of the Grade II contractions and had other minor variations from the Grade II used in Great Britain. (See Appendix C for a list of Grade I and 1/2 contractions.) Grade I and 1/2 remained the official braille in the United States from 1918 until 1932 when the Special American Uniform Type Committee recommended the adoption of Grade II in this country.

During these years there had been considerable discussion in this country concerning the value of Grade II braille. On one side was the argument that Grade II, with its many contractions, was too difficult. This was weighed against the fact that it saved 10-15% of the space required by Grade I and 1/2 [24] and the continuing desire for uniformity between our country and Great Britain. A study of the two grades of braille by Irwin and Wilcox[19] in 1929 evaluated not only the overall space saving of Grade II over Grade I and 1/2, but also the space saving of each contraction based on their occurence in four selected pieces of literature, which totaled slightly over 90,000 words. It was again suggested, as it had been in 1916, that many of the less frequently used contractions be dropped. However, the American committee finally accepted all of the British Grade II forms except:[24]

"1. The contractions and abbreviated words used mostly in religious literature were dropped from the system.

2. Dot 6, the capital sign of Grade One and a Half braille was accepted as the Grade Two capital sign.

3. Dots 4-6, the italic sign of Grade One and a Half braille was accepted as the Grade Two italic sign.

4. The abbreviation point (dot 3) used in Grade Two instead of the period to indicate the abbreviation of a word, was eliminated.

5. Five new abbreviated words were added to Grade Two as follows: "across," abbreviated "acr," "letter," abbreviated "lr," "necessary," abbreviated "nec," "quick," abbreviated "qk," and "together," abbreviated "tgr."

6. Contractions were to be omitted when they would interfere with legibility or pronunciation.

7. The Grade One and a Half braille percent sign was retained.

8. Letterpress was to be followed in the writing of Roman numerals."

Point number six of the above changes was the result of a difference in application of contractions in Great Britain and the United States. The English applied the principle of sequence, ie. a contraction was generally used wherever the sequence of letters it represented appeared in a word with a few exceptions, such as overlapping the parts of compound words. Americans, on the other hand, had developed the rule of syllabication while using Grade I and 1/2, ie. contractions were used only where they did not overlap any syllable break in the words.

M.S. Loomis[23] wrote a fairly complete summary of the debate between sequence ind syllabication in 1936 in which she described how the argument had grown from the use of Grade I and 1/2 in the United States and resulted in a compromise rule stating:

"Contractions forming parts of words should not be used when they are likely to lead to obscurity in recognition or pronunciation, and therefore they should not overlap well-defined syllable divisions. Word signs should be used sparingly in the middle of words unless they form distinct syllables. Special care should be taken to avoid undue contractions of words of relatively infrequent occurence."

The looseness of this rule lead to fairly wide variations between different braillists and braille publishers. In her discussion of the relative merits of the two types of applications Loomis brings out several points of interest.

"Many educators felt that words should be accurately divided for readers, although one of the chief purposes of contracted braille is to use as few signs as possible without sacrificing the clarity of the text. It is said that the fewer signs a word contains the more easily it is read--and the more naturally--for a reader can sense the entire word without being obliged to put a series of syllables together, thereby sensing the entire word with less speed. When fingers pass over a word more rapidly and a full sentence can be read in less time, the reader more readily obtains a complete thought and his method of reading more closely resembles that of a sighted person."

"One thing is noticeable, and that is the fact that blind readers themselves prefer a more liberal use of contractions. The more a blind man reads the more he favors sequence."

Sequence in Grade II braille is less serious than it is in Grade I and 1/2 braille. Additional contractions remove many cases of bad syllable overlapping.

"The words that suffer most through sequence are

readmit, reassure, reassemble etc. There are about seventy words in common usage that appear with this prefix re and with sequence the contraction ea is used. This probably is one of the worst parts of sequence and no one disputes this point, although the readers admit that the contraction is not confusing to them."

"Since the words that suffer the most through sequence are so greatly in the minority, the reader soon adjusts himself to the word, especially if the writing of it is always the same. He adjusts himself to the change in sound of fever and sever quite as readily as the sighted person adjusts himself to the pronunciation of bough, cough, through, rough, and though. In braille ough is written with the contractions ou and gh. This complete change in sound is mastered as easily by the reader of braille as it is by the sighted reader...The English language itself presents almost as many questionable uses as does sequence in braille."

"Sometimes in our effort to be kind we not only issue contradictory rulings and confuse the students attempting to learn the rules of braille, but we also insult the intelligence of the blind reader who is fully as capable of making the same distinctions as the sighted reader."

Current correct usage in our country, as defined by the 1959 Edition of English Braille, American Edition, indicates the same general ruling still exists, although it is much more precisely defined and more extensive examples are given. It is interesting to note that British usage continues to rely more upon sequence and American on syllabication, although in a few places their rulings are not consistent. For example, in Great Britain the contraction for "of" is correctly used in "profane," but not in "sofa." In the United States these same words are written differently, the contraction being used in "sofa," but not allowed in "profane."

It would appear that even in very recent years the writing of braille is not a fixed form, judging from the October, 1960, Addendum of twelve pages to the January, 1959, Edition of English Braille, American Edition. Admittedly, some of the changes are merely additional clarifications, but the removal of "andante," "roseate," and "caveat" from the examples of places where contractions are not legitimate would seem to indicate a change of opinion on how much emphasis is put on the syllabication of words.

Recently some research has been done of a nature similar to that previously conducted by the Uniform Type Committee on readability of various forms and contractions. Ashcroft has studied the effects of various types of contractions on reading errors, and consequently he suggested some revisions in the braille code. Also, as mentioned in the first section of this thesis, mechanization of braille printing suggests that some changes may still be desirable. This author has described the changes necessary for braille embossing directly from a typewriter encoding attachment.

As this summary illustrates, the history of writing for the blind has been one of constantly changing methods. It is therefore hoped that the suggestions put forward in the next section of this thesis will be considered as attempts at further improvement of a system which is the result of several centuries of study and work, and not as

an attempt to throw out the structure of a perfect system handed down unchanged from generation to generation.

RECOMMENDED CRITERIA FOR STUDIES OF BRAILLE CODES

Several factors need to be considered in evaluating braille contractions, either present or proposed, and the rules restricting their use. First, the basic reason for using contractions is to save space and reading time. Second, if the use of a contraction renders a word hard to recognize, then the time saving is lost and meaning may be obscured. Third, in order to increase the amount of braille material available, it is desirable to make the rules compatable with automatic translating machines.

The size of braille characters, required so that they can be distinguished by the sense of touch, and the thickness of braille paper, required to keep the dots legible for repeated readings, mean that braille material is bulky and heavy to store or handle. An encyclopedia may require fifteen to twenty feet of shelf space. The maximum speed for braille reading is limited by the sensing ability and mobility of the reader's fingers. The fewer characters his fingers must touch the faster a blind person can read. For these reasons, contracted braille was developed to reduce the number of characters.

It is fairly easy to mathematically evaluate the space saving effect of any contraction or rule. The number of characters saved can be evaluated by inspection. For example:

the use of "b" to represent "but" saves two characters, the use of one character to represent "ch" saves one space, the use of dot 5 - "f" for "father" saves four spaces, leaving out the space between "to," "into," or "by" and the word they precede saves one space. However, this measure alone does not indicate the space saving value; the frequency with which each contraction occurs must also be considered. This is a somewhat more difficult thing to measure since it requires counting the occurences in a sample of written material. The frequencies obtained will of course vary with the sample from which they are drawn. For this reason, it is desirable to use as large a sample as possible and to select the material to give a wide range of writing styles, such as newspaper, literary, and technical.

Much work has already been done counting the frequency of word occurences in our language. E.L. Thorndike and Irving Lorge[12] have counted well over thirteen million words of text. Unfortunately, they group the words into broad categories according to frequency, and generally their information has been of little assistance in this study. Godfrey Dewey[4] sampled slightly more than one hundred thousand words of widely diversified text and presents his findings as the number of occurences in his total sample. His findings are in agreement with Thorndike and Lorge as closely as can be checked. Because they provide a convenient scale of comparison,

they have been used to measure word frequencies in this study.

Dewey also counted syllable occurences, but because these were grouped by phonetic spelling, they were of no value in measuring frequency of braille contractions. Robert Irwin and Ruth Wilcox[19] counted about ninety thousand words of literary text, noting the frequency of each braille contraction. They then used this information to evaluate the space saving of Grade II braille over Grade I and 1/2 braille. Since some contractions did not appear at all in their study, it would seem that their sample text was not large enough or sufficiently diversified. A later section of this thesis will describe the development and operation of a program for an I.B.M. 709 or 7090 computer which will scan text and count the occurences of any letter sequences for which it is instructed to search. The combined results of this program and the Irwin-Wilcox study have been used to measure the frequency of occurence of part-word contractions in this thesis.

The final measure of space saving adopted here is the product of characters saved per occurence multiplied by the number of occurences in the sample measured:

$$S.S. = C.S. \times F$$

At some future time it might be desirable to divide this number by the total number of letters, punctuation marks, and spaces in the sample, and to express the quotient as a percentage:

$$\% S.S. = C.S. \times F \times 100\%$$

This would be a measure of the absolute space saving value of a contraction, but since it is agreed that some contractions are desirable, the comparative value obtained without counting characters is satisfactory.

It is somewhat more difficult to evaluate the effect that the use of a contraction has on reading. It is, of course, impossible to precisely measure the effect that one contraction has upon a particular reader's speed and comprehension. Too many factors, including context, other contractions, and vocabulary enter into any such measurement. However, some measure of the approximate effect of certain classes of contractions can be obtained. In his study of reading errors, Ashcroft [27] has defined an error index which can be applied to any word or groups of words. When words are grouped according to the contracted forms which appear in them, some idea of the hindrance of any type of contraction is obtained. Ashcroft defined his error index as:

$$E.I. = \frac{\Sigma e}{N_W}$$

Error index equals the sum or total number of errors associated with each word divided by the number of encounters of the words. Nevertheless, this does not give a precise measure of the difficulty of reading because, as Ashcroft states:

"Errors, for the purpose of this study, were broadly defined as has been indicated in Chapter III. The errors included everything that could be defined as a slight difficulty with the content, context and mechanics of the

paragraphs. The errors may be conceptualized as comprising a continuum of difficulties ranging from slight hesitations (including momentary difficulties) to the grossest of breakdowns in the reading process ... . The point to be noted in connection with this suggested continuum of errors is that the error total, 29,112, is not a homogenous group of errors of equal import for analysis of difficulty in reading braille."

Still further consideration must be given to the point that what is difficult for one reader or group of readers is not necessarily difficult for readers of different backgrounds or abilities. People who are blind from birth or early childhood and grow up using only braille as a means of communication are generally, though not always, more proficient at reading highly contracted forms of braille, such as Grade III which is used by a few people in this country for personal notes, than are people who must learn braille as adults already familiar with ink-print and script, and without a highly developed sense of touch. In general, evaluation of the contractions from the point of readability must be semi-subjective. The points which will be considered in this study are (1) frequency, in as much as frequently occuring contractions usually are rapidly learned, (2) logic used to derive contractions, such as some form of mnemonic device, (3) difficulty as indicated by Ashcroft's study.

In order to consider compatability with translating machines it is necessary to have some form, or possible forms of machine in mind. At the present time, the author knows of four types of machines for translating into braille.

Mrs. Ann Shack and R.T. Mertz[26] of the I.B.M. Corporation have programmed a 704 computer to translate into Grade II braille for the American Printing House for the Blind. This program contains the rules concerning the use of each braille contraction. These are compared with the circumstances found in the text with any sequence of letters equivalent to a contraction. Some rules, such as the one stating that "word signs 'a,' 'and,' 'for,' 'of,' 'the,' and 'with' should follow one another without a space between if there is no natural pause between them," have been mathematically interpreted. In this case, it was determined that the space is generally eliminated when a conjunction precedes a preposition or an article, or when a preposition precedes an article. On the other hand, the space was generally retained when a conjunction follows a preposition or an article, or when a preposition follows an article. From this assumption it is possible to assign the number 4 to conjunctions, 2 to prepositions, and 1 to articles, subtract the value of the first word from the value of the second word, and if the remainder is greater than zero eliminate the space.

Rules concerning pronunciation are accounted for by the table used to list contractions. This table lists all the contractions and also any special words or letter combinations which may be necessary because of pronunciation or other rules. For instance, the contraction for "ea" is preferred to "ar"

in "dear," "fear," etc., and an entry for the sequence "ear" takes care of this rule. Unfortunately, to allow for all problem words would most likely require a list too large for the computer, and furthermore, such a list could probably be compiled only from experience. The current practice therefore, is to select samples from a book to be translated and to use these to correct the list on the assumption that most authors have consistent vocabularies. This program also sets the format of the braille printing, such as centering titles and determining the ends of lines. It should be noted that this program has been successful in translating trial books, but that it is still an expensive means of translating and saves little over the use of human translators.

A second type of Grade II braille translator was designed by R.J. Dirkman.[28] This device operates as an attachment to a typewriter and requires that the typist know when a contraction is employed. A rotating disc photomemory is used to store a table of the braille codes for each letter, sign and contraction. When single letters are typed the table of characters finds the sign by an optico-electrical coincidence indicator and transmits a coded electrical signal corresponding to the braille character. When a contraction occurs, the typist depresses a foot switch which causes the electrical signals for the characters of the contraction to be superposed. By using certain coding techniques this produces a unique

signal for each contraction. The table then finds the corresponding braille code. If the contraction consists of more than one braille character, the characters are transmitted sequencially. This device, while very helpful for volunteer braillists, is not suitable for a completely automatic system because it requires someone to determine where each contraction must be used.

The remaining two devices only translate to Grade I braille. One is a typewriter attachment being designed at M.I.T. by David Eglinton[30] which prints one braille character for each typed character, except the capital sign is used. This device uses a seven beam optical system which is coded by the location of projections on movable bars connected to each key of the typewriter. It should be of great benefit in allowing blind people to proofread their typing, and for making other material more readily available to blind people where an inexact form of Grade I braille is more desirable than nothing. Current planning is for this device to be used with the high speed electric brailler being designed at M.I.T. by Daniel Kennedy and this author.[18] Either device, particularly the brailler, will also be of use in conjunction with any other equipment producing or requiring electric signals in compliance with the standard braille punched tape codes.

The other Grade I braille device was designed by Sidney Friedrich[31] to translate from teletypesetter punched tape to

correct Grade I braille, including number signs and other braille composition marks. Combinatorial switching circuits employing electromagnetic relays are used to directly translate letters read from the six channel teletypesetter tape, and to punch them on a six channel tape corresponding to the braille code. Sequencially operating circuits are also used to handle shift operations on the teletypesetter tape, numbers, and braille composition signs. Many of these operations require stopping the reader, the punch, or both, and holding information from one character until several can be translated. For example, when any digit is read on the teletypesetter tape, that tape is stopped and the number remembered while the number sign is punched on the braille tape, then the number is punched. The translator must also remember that it is writing a number, for if the next character read is also a number, the number sign is not repeated. When a space is used, the effect of the number sign is terminated and translating proceeds normally.

From a study of these devices some idea of an automatic translator can be formulated. Such a device would be capable of recognizing sequences of letters, including spaces and punctuation, which are wholly or partially contracted in braille. The inclusion of spaces and punctuation would allow the machine to tell whether the letters of interest appeared as a whole word or the beginning, middle, or end of a word.

The machine output would be a series of electrically coded braille cells, still including spaces and punctuation. In many cases the sequence, and therefore the output, would consist of one character. Standard line length format could be produced by the machine, although titles and other features should be programmed before giving the material to the machine to translate. In general, this material would have to be added to the tapes used in setting type for regular publications anyway.(36) Therefore, requiring this format is little extra burden on the machine operator compared with the additional complexity necessary to have the translating machine handle all format problems.

This rough idea of a translator has been developed considering a compromise between a reasonable form of braille and a desire to keep the translator as inexpensive, and therefore uncomplex, as possible. In general, it requires that contractions be recognizable by their sequence of letters without regard to some of the peculiarities of our English language.

EVALUATION OF CURRENT GRADE II CONTRACTIONS

The contractions currently used in Grade II braille will be evaluated using the three criteria developed in the last section: an ability to reduce space, readability, and translatability. Dewey's [4] word count will be used as the measure of frequency for whole word contractions for calculating space saving. The results of Irwin and Wilcox [19] combined with the results of the computer program discussed later in this thesis will be used in evaluating the space saved by part word contractions. Readability will be judged by the results of Ashcroft's [27] studies and the comments from other sources, such as MacKenzie [10] and his quotes from Mr. H.M. Lochead, the Headmaster of the Royal School for the Blind in Edinburgh, Scotland, and Mr. J. Lorimer, Master of the Birmingham Royal Institute for the Blind in Birmingham, England. These last three men, MacKenzie, Lochead, and Lorimer are all blind. The translatability of contractions is determined by the degree to which their use can be allowed or disallowed solely on the basis of the contraction itself and the characters immediately preceding and following it, without regard to meaning, pronunciation or syllabification.

Since the entire system of Grade II braille contractions is too complicated to study as a unit, it has been divided into the following categories, each of which will be

individually discussed in the light of the three major criteria described above. The categories to be studied include: alphabetic contractions, other whole word only contractions, whole and part word single cell contractions, part word only single cell contractions, initial letter contractions, final letter contractions, and short form words. After these categories of contractions have been examined, the general rules governing all contractions will be discussed and some comments on the effectiveness of the braille contraction system will be made.

Alphabetic Contractions

Alphabetic contractions are words which are represented by a single letter in braille. Twenty-one such words are represented by their first letter; "it" is represented by the letter "x," and "as" is represented by the letter "z."

Most of these words rate well as space savers within the limits imposed by contracting them or their first letter. Table I summarizes the space saved by each alphabetic contraction as well as some other frequently occurring words of the same first letter. After accounting for part word contractions which could be used in these words and those words which have been assigned other braille characters, it can be seen that most of these words are good selections from the point of space saving. More space could be saved by substituting

TABLE 1

ALPHABETIC CONTRACTIONS

LETTER	CONTRACTION	F.	C.S.	S.S.	E.I.	OTHER WORDS	F.	C.S.	S.S.	COMMENT
a					.01					
b	but	504	2	1008	.02	be	846			1
						been	328	2	656	2
						by	600			1
c	can	197	2	394	.02	come	123	1	123	2
						could	133	1	133	1
d	do	203	1	203	.03	day	101	1	101	1
						did	100	2	200	
e	every	124	3	374	.13					
f	from	433	3	1299	.11	first	131	1	131	1
						for	1035			1
g	go	73	1	73	.02	get	89	2	176	
						good	106	3	318	1
						great	134	3	402	1
h	have	617	3	1851	.02	had	411	1	411	1
						has	370	2	780	
						his	517	2	1034	
i					.01					
j	just	86	3	254	.07					
k	knowledge	24	5	120	.45	kind	31	2	62	2
						know	102	1	102	1

F. = Frequency per 100,000 words
C.S. = Characters saved
S.S. = Space saved
E.I. = Error index

COMMENT

1 = This word has a contraction
2 = This word is written with a part word contraction

TABLE 1 CONTINUED

LETTER	CONTRACTION	F.	C.S.	S.S.	E.I.	OTHER WORDS	F.	C.S.	S.S.	COMMENT
l	like	113	3	339	.07	little	111	1	111	1
m	more	210	3	630	.03	me	257	1	257	
n	not	589	2	1178	.03					
o	no word used									
p	people	163	5	815	.05					
q	quite	27	4	108	.24	question	23	1	23	1
r	rather	32	3	96	.15	read	38	2	76	2
						right	91	3	273	1
s	so	300	1	300	.06	she	188	1	188	2
						should	118	1	118	1
						some	152	1	152	1
						such	134	2	264	1
t	that	1345	2	2690	.02	the	7310			1
						this	572			1
						to	2924			1
						too	57	2	114	
u	us	123	1	123	.07	under	108	1	108	1
						up	204	1	204	
v	very	145	2	290	.03					
w	will	445	3	1335	.01	we	529	1	529	
						was	839			1
						which	454			1
						with	727			1
x	it	1216	1	1216	.01					
y	you	775	1	775	.03					
z	as	782	1	782	.01					

either "great," "good," or "get" for "go," "right" for "rather," and "up" for "us." It is also possible that some words might be represented by some key sound other than their first letter, although no check of such possible words has been made.

Ashcroft's study indicated that, as a group, alphabetic contractions resulted in fewer errors than any other braille forms, including fully spelled words. This indicates that, generally, these contractions add much to the value of braille. The studies of the Uniform Type Committee, which in its 1909 report states, "Unequivocal (upper-cell) whole-word signs facilitate reading," and comments by MacKenzie and others concur in this finding. According to Ashcroft, a few of the less frequently occurring contractions did cause some errors. The individual error indices of the alphabetic contractions are listed in Table I with the information on space saving. It should, however, be remembered that Ashcroft's study was on second to sixth grade school children who would be expected to have less contact with these words. In addition, Ashcroft's study did show a marked improvement on the problem words in the upper grades. He did suggest that the word "kind" be substituted for "knowledge," "right" for "rather," and "too" for "that." His first two were recommended on the basis of frequency, hoping that the more frequently used words would aid memory. Table I indicates that "kind" is not enough more frequent to warrant the problems of change.

Ashcroft's other recommendation is claimed to be phonetically more consistent; however, the difference in frequency, (57 to 1,345) should far outweigh the phonetic problems.

The alphabetic contractions are also good with respect to mechanical translation. These words, viewed as letter sequences by a machine, cannot, according to the rules of braille, be in contact with any other letters or contractions, except that they may be preceded by "to," "into," or "by." The rules for these words would be presented as what may precede and follow the contractions, or what may not. Both of these cases are summarized here:

May be preceded by:	May be followed by:
space	space
hyphen	apostrophe
punctuation	hyphen
	punctuation
May not be preceded by:	**May not be followed by:**
any letter	any letter

These rules apply to the letter sequences as they would be found in ink-print by the translator. Other braille characters, such as the contractions for "to," "into," or "by" and the composition signs may touch these words in the braille copy, but these would not effect the translator as it searches for possible contractions. The current braille rules allow the use of alphabetic contractions in compound words which are

hyphenated and in English contractions, such as "can't" and "you'll." The present rules do forbid the use of these contractions "in rare or colloquial forms," such as "you'n." It would be desirable, for the sake of a translator, to change this rule.

In summary, alphabetic contractions are generally desirable, however, it might be advisable from the point of view of space saving to substitute "great" for "go," and "right" for "rather." Ashcroft would also consider the latter an improvement in readability. Rule 36 b should be changed to allow the use of an alphabetic contraction before the apostrophe in all words, even colloquial ones.

Other Whole Word Contractions

This classification consists of words like "child" which are similar to alphabetic contractions except that they are represented by the braille character which also represents their first two letters. These words include "was," "were," "his," "by," and "to," and the word "into," which is really a combination of two contractions, but which is treated as a single contraction by the braille rules.

Table III shows the space saving and Ashcroft's error indices of the words in this group. It may be seen that, with the exception of "child" and "out," the words represented by their first two letters are the best space saving words

available within the limitation of these first letters. These words save a great deal of space, and all except the word "into" are among the fifty most common words in the English language; "into" is among the seventy-five most common words in the English language. While no comparison of the space saving of these words is given here, they will be further discussed in the comments on the general efficiency of braille.

Ashcroft's study divided these words between two of his categories. "Child," "shall," "this," "which," "out," and "still" are upper contractions while the remaining words are lower contractions. Upper contractions, as a group, rate as being slightly more difficult than fully spelled words, but are easier to read than the average for all contractions. These words also fall under the favorable comments which the Uniform Type Committee cited for alphabetic contractions. Nevertheless, Ashcroft does report that "which" was often confused with other common words beginning with "wh," but he did not suggest any corrective changes.

Lower signs are generally considered more difficult to read, primarily because they tend to cause a blind reader to lose his vertical alignment and in so doing he mistakes lower signs for characters of the same shape in the upper part of the cell. "was," "were," and "his," however, have low error indices as reported by Ashcroft, which is probably due to the

TABLE II

OTHER WHOLE WORD CONTRACTIONS

BRAILLE CHARACTER	CONTRACTION	F.	C.S.	S.S.	E.I.	OTHER WORDS	F.	C.S.	S.S.	COMMENT
ch	child	24	3	72	.17	change	21	4	84	2
						character	17	1	17	1
						children	35	1	35	1
sh	shall	120	3	360	.21	she	188	1	188	2
						should	118	1	118	1
th	this	572	2	1144	.10	that	1345			1
						the	7310			1
wh	which	454	2	908	.39					
ou	out	203	1	203	.03	our	331	1	331	2
st	still	58	3	174	.20					
en	enough	44	2	88	.41					
	was	839	2	1678	.05					
	were	305	2	610	.03					
	his	517	2	1034	.11					
	by	600	2	1200	.09	}				
	to	2924	2	5848	.01	}	S.S. figure slightly high since it includes space not used after these contractions.			
	into	166	3	498	.04	}				

F. = Frequency per 100,000 words
C.S. = Characters saved
S.S. = Space saved
E.I. = Error index

frequency of their occurence. "To," "into," and "by" also have low error indices resulting from not only their frequent use but also from the fact that the space following them is often omitted and they are joined to the word following, thereby reducing greatly the vertical alignment problem. The word "enough" does seem to cause considerable trouble in reading. Ashcroft attributes this to the multiple use of the braille character, which represents "en" when part of a word, and "enough" when standing alone. In any case, the word apparently presents a problem in reading, and for this reason, as well as its comparatively low space saving effect, consideration might be given to dropping it from the braille contractions. Some writers express the feeling that the signs known as "lower g" and "lower j" are suggestive of the words "were" and "was." Lochead suggests using the contraction for "er" to represent the word "were." However, Ashcroft's study indicates little need for these changes.

This set of whole word contractions is logically subdivided into three groups for evaluation of their machine translatability. The first group consists of the upper signs, "child," "shall," "this," "which," "out," and "still." These words are governed by exactly the same rules as the alphabetic contractions and therefore, everything said about those contractions concerning mechanical translation applies here. These sequences of letters may be contracted by the machine if

they are preceded by spaces, hyphens, punctuation, or composition signs and followed by spaces, hyphens, punctuation, or apostrophes.

The braille characters for "enough," "was," "were," and "his" are lower signs which are also used to indicate punctuation. Therefore, the rules limit their use to avoid possible confusion with punctuation or vertical alignment in reading, which might come from the use of these words in contact with punctuation. The rules for these words, summarized as they are most easily presented to the computer, state that the contractions are to be used if and only if the sequence of letters is:

preceded by:	followed by:
space	space
capital sign	
italic sign	

The last group of words in this set is "in," "into," and "by." The current rules concerning the use of these three contractions are impossible to apply in a mechanical translator. Rule 41 states, "There shall be no space between the lower-sign contractions to, into, and by and the word which follows if there is no natural pause between them. If in doubt about the pause, they should be joined. Whenever into must be written out, the in sign should be used." The rule admits a possibility of doubt for a human translator, and so

far no way has been determined to program a natural pause in our spoken language into a computer. It becomes apparent that this rule has the further subtlety of meaning, that when a natural pause does exist and the space must be used, the contraction cannot be used. For instance, there is the example cited in English Braille, American Edition:[20]

He was passed by while others were taken.

There are two ways of changing this rule so that it becomes clear and uniform for all applications. Either eliminate the space at all times or use it at all times. This author's feeling leans toward the former on the basis that any pause about which there is no doubt will be marked by punctuation. In addition, lower signs standing alone tend to cause vertical alignment problems to readers, and this method of writing will save the most space. In either case, there should be consistency in the use or abolition of the space.

The remaining rules are easier to interpret mechanically. These contractions are used when the sequence of letters is:

Preceded by:	Followed by:
space	space
punctuation	composition sign
composition sign	abbreviation for a special ink-print symbol such as $

but not when they are both preceded and followed by a capital sign, or when they are both preceded and followed by an italic

sign. When these contractions are used and followed by a space, the space is eliminated in braille.

In summary, these whole word contractions generally seem to add more than they detract from braille. However, the value of using a single cell contraction for "enough" seems to be doubtful and consideration should be given to dropping this contraction. Rule 41 should be revised so that the contractions for "to," "into," and "by" are always used and written without a space between them and the word following, unless they are followed by punctuation. There is no reason to believe that this will cause readers any difficulty in understanding what they read. In fact, it will probably increase reading speed because of the greater consistency with which these words are embossed.

Whole And Part Word Single Cell Contractions

There are seven sequences of letters which are contracted, either when they appear as whole words or parts of words. These are "and," "for," "of," "the," "with," "in," and "be." Table III summarizes the space saving data for these words. All seven of these words are among the twenty most common words in English. Their space saving effects would be quite high even if these contractions could not be used to form parts of words also. It is interesting to note the discrepancies between the counts of Dewey and those of Irwin and Wilcox.

TABLE III

WHOLE AND PART WORD SINGLE CELL CONTRACTIONS

CONTRACTION	C.S.	W.W. F.	W.W. S.S.	TOTAL F.	TOTAL S.S.	E.I.
and	2	3280	6560	3785	7570	.01
for	2	1035	2070	1243	2486	.02
of	1	3998	3998	3521	3521	.02
the	1	7310	7310	7650	7650	.01
with	2	727	1454	930	1860	.04
in	1	2116	2116	4284	4284	.01
be	1	846	846	801	801	.00

C.S. = Characters saved

W.W.F. = Whole word frequency

W.W.S.S. = Whole word space saved

TOTAL F. = Total frequency, including part word usage

TOTAL S.S. = Total space saved

E.I. = Error index

For the contractions "of" and "be," counting their use both as whole and part words, Irwin and Wilcox found only 3,224 and 734 occurrences respectively in 91,564 words or 3,521 and 801 occurrences respectively per 100,000 words. In contrast, Dewey, while counting whole words only, found 3,998 and 846 occurrences respectively in 100,000 words. This is an indication of the possible effects of different samples of English text. Nevertheless, accepting either figure results in favorably space saving effects for these words.

The error indices of these characters when appearing as words are among the lowest which Ashcroft measured. MacKenzie[10] states that "The English signs for AND, FOR, etc. are in essence arbitrary, but, carrying these values wherever they appear, they pass out of the class of the arbitrary into the mnemonic." Earlier in his book he stated that the secret of a good contracted system seemed to include the greatest possible use being made of the mnemonic principle. These contractions appear to cause somewhat more difficulty when they appear as parts of words. Ashcroft states, "The words in which they appeared as parts have error indices indicating much greater difficulty." However, a study of his individual word error indices indicates that with the exceptions of "forget," "candy," "without," (which also contains a contraction for ou), and a few words containing "in," which is a lower sign, his error indices for words

with these contractions are under .07, which is quite reasonable.

A discussion of translatability once again requires dividing the words into upper and lower contractions. The upper contractions, "and," "for," "of," "the," and "with" are used in any part of a word and are preferred to other contractions when there is a choice and equal amounts of space would be saved. In general, these contractions may be used wherever the sequence of letters is found without regard to the characters preceding or following them.

The words "in" and "be" are lower signs and therefore, braille has rules concerning their use to avoid vertical alignment problems. The general rule is that two or more lower signs may not follow each other unless they are in contact with an upper sign. The contraction for "be" is further restricted, since it is used only as the first syllable of a word or a whole word. The rules for the contraction "in" may then be reduced to allowing the use of the contraction anywhere except when the above rule concerning lower signs is violated. It should also be noted that in this case the capital sign and the italic sign are not counted as either lower or upper signs. The rules for "be" are the same with the additional stipulation that this contraction cannot be immediately preceded by a letter or followed by an apostrophe. This interpretation

will require revision of the current rules so that "be" need not be a syllable in order to be contracted.

In summary, these whole and part word contractions are aids in space saving and cause no reading difficulty. They generally do not present a problem to machine translation except that Rule 43 must be revised to allow the contraction of "be" when it is the beginning of a word, but not a syllable.

Part Word Single Cell Contractions

The twenty-three single braille cell contractions which can be used only as part words are listed in Table IV, along with the data on their space saving effect. It is apparent that there is a wide range from 4,000 to less than 50 characters per 100,000 words. This would indicate that, while as a group these contractions are quite useful, some of them such as "bb" and "gg," with frequencies of 47 and 71 respectively, do not reduce space very much. While there is overlapping, the upper contractions, having frequencies from 405 to 4,008, are generally better space savers than the lower contractions, having frequencies from 47 to 1,939.

It is interesting to note that Ashcroft's studies reveal generally more reading difficulty with words containing lower contractions. In particular, he sights "bb," "cc," "dd," "ff," and "gg" as appearing in words which were especially difficult. Whereas, he states, "Category III (upper) contrac-

TABLE IV

PART WORD SINGLE CELL CONTRACTIONS

Contraction	Frequency	Characters Saved	Space Saved
Upper signs			
ar	2458	1	2458
ch	1098	1	1098
ed	3943	1	3943
er	4008	1	4008
gh	705	1	705
ou	1633	1	1633
ow	1219	1	1219
sh	1146	1	1146
st	2769	1	2769
th	2469	1	2469
wh	1084	1	1084
ble	405	2	810
ing	2826	1	2826
Lower signs			
en	3344	1	3344
com	395	2	790
con	482	2	964
dis	264	2	528
bb	47	1	47
cc	141	1	141
dd	112	1	112
ea	1939	1	1939
ff	219	1	219
gg	71	1	71

tions having only part word meanings tended to have lower error indices...." The Uniform Type Committee also found that reading was generally slowed down by lower contractions.

Further study on a wider range of people, including adult braille readers, is probably needed, but there is definitely a serious question as to whether or not all of the lower part word contractions are justified.

The translatability of these part word signs also depends upon whether they are upper or lower contractions. The upper signs may be used wherever they appear, provided some other contraction does not save more space. The only exception is that "ble" and "ing" may not be used at the beginning of a word. The lower signs are subject to further constraints since most of these braille characters have multiple meanings, and also because of possible vertical alignment problems. "En" is the only lower sign which may be used wherever it occurs, except as prohibited by the general rule requiring that if two or more lower signs follow one another, they must be in contact with an upper sign. "Com," "con," and "dis" can only be used at the beginning of words. In the case of "con" and "dis" this again requires a change of the rule which currently restricts these to be first syllables. The contractions "bb," "cc," "dd," "ea," "ff," and "gg" are not allowed at either the beginning or end of words, but may only be used between other letters or

contractions in a word.

In summary, in view of all three criteria for space saving, readability, and translatability, careful consideration should be given to dropping some of the lower part word contractions. Also, Rule 43 should be revised to allow using "con" and "dis" when they are not first syllables. This involves very few words since these sequences are almost always the first syllable anyway. Webster's New Collegiate Dictionary[13] lists only "conche," "cone," "conifer" and related words, "disc," "dish," "disk," and "disulfide" as exceptions to the above statement. These words would be easily recognized after a short period of adjustment among present readers and the change should not be any more difficult for new readers to learn, particularly since "com" is currently used without regard to syllabication.

Initial Letter Contractions

Initial letter contractions take two braille cells. The first cell contains one of three braille characters: dot 5, dots 4 and 5, or dots 4,5, and 6, and the second cell contains the initial letter of the contracted word. These contractions may be used either as whole words or as parts of words, provided that they retain their original sound. In addition, these contractions are subject to a few special restrictions which will be discussed under translatability.

Table V summarizes the space saving effect of these contractions including their use as whole words only, based on Dewey's data, and as both whole and part words based on the Irwin and Wilcox study. A comparison of these two sets of data indicate some discrepancies, such as the word "many," which Dewey found 104 times, while Irwin and Wilcox counted only 49 times, and the word "world," which Dewey counted 103 times, but which Irwin and Wilcox found only 34 times. These discrepancies must be attributed to the more varied sample used by Dewey, which included newspaper text, while Irwin and Wilcox limited their sample to four literary works. It is also probable that some of the differences where Irwin and Wilcox found more occurrences of a word are due to the difference in the two samples. Some examples of this are "father," 48 to 17, and "lord," 27 to less than 10. Many of the contractions where Irwin and Wilcox found considerably greater frequencies are due to the fact that these contractions also occur frequently as part words.

The space savings of the initial letter contractions are generally less than those for single cell contractions, because of both lower frequency and fewer characters saved per occurrence. In fact, many of these contractions are of such little value in space saving as to suggest that they be dropped.

Ashcroft found that multiple cell contractions (initial

TABLE V

INITIAL LETTER CONTRACTIONS

Contraction	C.S.	W.W.F.	W.W. S.S.	T.F.	T.S.S.	W.W. E.I.
cannot	4	58	232	62	248	.22
day	1	101	101	190	190	-
ever	1	51	51	318	318	.21
father	2	17	34	48	96	.04
here	1	107	107	82	82	.12
had	1	411	411	844	844	.02
know	1	102	102	323	323	.02
lord	2	-	-	27	54	.51
mother	2	20	40	24	48	.02
many	2	104	208	49	98	.04
name	2	40	80	45	90	.11
one	1	368	368	633	633	.01
part	1	79	79	182	182	-
question	4	23	92	-	-	.37
right	2	91	182	111	222	.06
some	2	152	304	344	688	.06
spirit	4	14	56	25	100	.55
time	2	205	410	202	404	.01
under	2	108	216	152	304	.12
upon	2	129	258	153	306	.41

C.S. = Characters saved
W.W.F. = Whole word frequency
W.W.S.S. = Whole word space saved
W.W.E.I. - Whole word error index
T.F. = Total frequency
T.S.S. = Total space saved

INITIAL LETTER CONTRACTIONS CONTINUED

Contraction	C.S.	W.W.F.	W.W. S.S.	T.F.	T.S.S.	W.W. E.I.
work	2	83	166	77	154	-
word	2	19	38	87	174	.07
world	3	103	309	34	102	.04
young	2	41	82	80	160	.04
there	1	306	306	384	384	.05
these	1	152	152	139	139	.24
their	1	315	315	273	273	.09
character	4	17	68	29	116	.84
through	2	78	156	93	186	.10
those	2	104	208	112	224	.36
where	1	83	83	159	159	.20
whose	2	42	84	35	70	.75
ought	1	16	16	174	174	.25

and final letter) were the second most difficult category of words for readers. He states, "Even though much of the difficulty came from several infrequently appearing words such as 'character,' 'lord,' and 'spirit' many useful and frequently appearing whole words such as 'these,' 'those,' 'whose,' 'where,' 'upon,' 'ever,' and 'cannot' seemed to present an inordinate amount of difficulty because of the nature of their configuration as multiple cell braille contractions." He suggests the replacement of "character" by "change," and "spirit" by "same" in order to improve the usefulness of these characters. It is interesting to note that the 1916 Report of the Commission on Uniform Type for the Blind (17) recommended that the contraction for "cannot," "father," "lord," "another," "name," "right," "spirit," "word," "world," "young," "character," "those," and "whose" be wholly suppressed because they showed low recurrence and were represented by characters with low time and accuracy values.

As the rules concerning use of these contractions now stand, they are impossible to mechanically translate. This is because these contractions can only be used "when they retain their original sound." It is not possible without entering a complete dictionary into some form of memory, for a machine to differentiate sounds from the spelling of English words. Further changes necessary to allow mechanical

translation are: (1) allowing the contraction "one" to be used without requiring that the "o" and the "n" come in the same syllable, (2) allowing the contraction for "part" to be used in forms of the word "partaken," (3) dropping the requirement that the contraction "some" retain its original sound and form a complete syllable. The comments concerning pronunciation also hold with regard to syllabication in our language.(37) If these rules are changed than the initial letter contraction sequence may be contracted whenever they occur.

In summary, it should be said that while many of the initial letter contractions are of considerable value in space saving, many others are of questionable worth, particularly considering the general difficulty in reading these contractions. Therefore, several of these words should probably be written fully spelled in braille. Rule 45 should be revised to eliminate the pronunciation requirement. Rules 45 a and 45 d should be dropped to eliminate the syllabication requirement, and Rule 45 c should be omitted also.

Final Letter Contractions

There are fourteen two cell contractions which are formed using the last letter of the contraction as the second cell preceded by one of three braille characters: dots 4 and 6, dots 5 and 6, or dot 6, as the first cell.

These contractions usually occur at the ends of words although they sometimes appear in the middle. Braille rules prohibit their use at the beginning of words, since the first cell characters are also used as composition signs when they appear immediately before the first letter of a word or before a single letter.

The space saving data summarized in Table VI indicates that these contractions, with the exception of "ount," save a reasonable amount of space. "Tion" and "ation" are outstanding space savers even though they might, at first thought, appear to detract from each others usefulness.

Ashcroft's study makes no particular mention of final letter contractions and contains only partial data on their error indices. The E.I. column of Table VI lists in parentheses the words which he used containing final letter contractions without containing other contractions also. This small sample hardly seems sufficient to evaluate these contractions since so many other factors could enter into the error indices of these words. J. Lorimer[10] comments, "I consider that the least satisfactory of all Braille signs are the final contractions. With the possible exception of ENCE, they are all clear to the touch, but many readers have found them difficult to learn and to remember. I think this is due to their consisting of the final letters of the sequence they represent." Before any evaluation of the

TABLE VI

FINAL LETTER CONTRACTIONS

Contraction	F.	C.S.	S.S.	E.I.
ound	266	1	266	.02 (found)
ance	267	2	534	.26 (dance)
ence	235	1	235	.06 (fence)
ong	276	1	276	.02 (long)
ful	142	1	142	-
sion	148	2	296	.23 (mansion)
tion	500	2	1000	-
ation	441	3	1323	-
less	86	2	172	.33 (unless)
ness	249	2	498	-
ount	87	1	87	.07 (country)
ment	266	1	266	.14 (moment)
ity	325	1	325	.09 (city)
ally	190	1	190	.22 (usually)

F. = Frequency

C.S. = Characters saved

S.S. = Space saved

E.I. = Error index

readability of final letter contractions is made, further experimental studies should be made.

The rules for usage of final letter contractions state that they should be used in the middle or at the end of a word; they are not to be used at the beginning of a word, as a whole word, or when preceded by the hyphen or the apostrophe. For the mechanical translator it is sufficient to say that these contractions are used whenever they are immediately preceded by a letter. However, two exceptions to the above rule would have to be dropped. One states, "the contraction 'ness' should be used in such easily read words as 'baroness,' 'governess,' and 'lioness,' but not in 'chieftainess.' Neither a machine, nor this author and many other people can distinguish which words are easily read. It seems as though the use of "ness" should be allowed at all times. The second exception states, "the contractions 'ity' and 'ally' should not be used where 'y' has been added to a base word," such as in "fruity" and "squally." A mechanical translator cannot distinguish these words from others where "ly" is added to a base word, such as "usually" and "really," or where the contraction is part of a base word, such as "city" or "deity." The last four words are all examples cited as correct usage of these contractions. It would appear that the rules should allow "ity" and "ally" to be used without regard to any base word and suffix criteria.

In summary, the final letter contractions are justified as space savers, but need further study before their readability can be judged. Exceptions b. and c. to Rule 46 should be discontinued so that "ness," "ity," and "ally" can be used at all times.

Short Form Words

The seventy-six short form words which are written in abbreviated form use the letters and contractions which have already been discussed. A complete list of these words, with their abbreviated forms, is found in Appendix A. Table VII contains the space saving and error index data on these words. It may be seen that while some of the short form words save a significant amount of space, others contribute very little toward the reduction of bulk in braille. Many of these words are in the range frequences where the text material sampled makes a great deal of difference. This undoubtedly accounts for the wide discrepancies between Dewey and Irwin and Wilcox, as seen in the following examples, with Dewey's occurrences the first: "him" 234 to 540, "today" 85 to 4, and "you" 214 to 90. It also accounts for the fact that some words, such as "braille," "conceiving," and "oneself," did not occur in the list from either count, while it is obvious that these words are used in English writing, even if very occasionally. However, it must be remembered that Dewey did not list any

TABLE VII

SHORT FORM WORDS

CONTRACTION	C.S.	W.W. F.	W.W. S.S.	T.F.	T.S. S.	E.I.
about	2	153	306	235	470	.03
above	2	25	50	18	36	.10
according	4	17	68	12	48	.54
across	3	14	42	-	-	.04
after	2	107	214	112	224	.06
afternoon	5	31	155	-	-	-
afterward	4	< 10	< 40	8	32	.33
again	2	62	124	96	192	.07
against	2	73	146	72	144	.02
almost	2	37	74	51	102	.06
already	3	27	81	25	75	.20
also	2	69	138	70	140	.23
although	2	18	36	11	22	.16
altogether	2	13	65	12	60	.49
always	3	62	186	88	264	.10
because	4	108	432	56	224	.03
before	3	139	417	97	291	.04
behind	2	24	48	34	68	.08
below	1	< 10	< 10	9	9	.15
beneath	2	< 10	< 20	9	18	.22
beside	3	< 10	< 30	10	30	.08
between	3	60	180	72	216	.16
beyond	3	19	57	33	99	.42
blind	2	< 10	< 20	10	20	.41
braille	4	< 10	< 40	0	0	.03

C.S. = Characters saved
W.W.F. = Whole word frequency
W.W.S.S. = Whole word space saved
T.F. = Total frequency
T.S.S. = Total space saved
E.I. = Error index

SHORT FORM WORDS CONTINUED

CONTRACTION	C.S.	W.W. F.	W.W. S.S.	T.F.	T.S. S.	E.I.
children	2	35	70	32	64	.02
conceive	3	< 10	< 30	5	15	.63
conceiving	2	< 10	< 20	0	0	.45
could	2	133	266	146	292	.02
deceive	4	< 10	< 40	8	32	.45
deceiving	3	< 10	< 30	0	0	-
declare	3	< 10	< 30	10	30	.37
declaring	2	< 10	< 20	0	0	-
either	2	36	72	32	64	.18
first	2	131	262	-	-	-
friend	3	17	51	-	-	-
good	2	106	212	122	244	.04
great	1	134	134	134	134	.03
herself	3	< 10	< 30	11	33	.05
him	1	234	234	540	540	.11
himself	4	51	204	91	364	.07
immediate	6	14	84	8	48	.72
its	1	208	208	185	185	.05
itself	4	26	104	36	144	.07
letter	3	36	108	-	-	.04
little	4	111	444	182	728	.02
much	1	104	104	83	83	.05
must	1	163	163	124	124	.03
myself	3	33	99	25	75	.02
necessary	5	35	165	-	-	.24
neither	2	13	26	32	64	.25
o'clock	4	21	84	9	36	.03

SHORT FORM WORDS CONTINUED

CONTRACTION	C.S.	W.W.F.	W.W.S.S.	T.F.	T.S.S.	E.I.
oneself	3	< 10	< 30	0	0	.42
ourselves	4	20	80	9	36	.19
paid	2	16	32	16	32	.17
perceive	3	< 10	< 30	10	30	.56
perceiving	2	< 10	< 20	1	2	.47
perhaps	3	26	84	52	156	.09
quick	3	< 10	< 30	-	-	.07
receive	4	< 10	< 40	25	100	.38
receiving	3	< 10	< 30	4	12	.49
rejoice	4	< 10	< 40	6	24	.60
rejoicing	3	< 10	< 30	0	3	.42
said	2	161	322	242	84	.02
should	2	118	236	98	196	.14
such	1	132	132	111	111	.18
themselves	4	34	136	98	396	.09
thyself	3	< 10	< 30	5	15	-
today	2	85	170	4	8	.06
together	3	25	75	-	-	.12
tomorrow	5	11	55	4	20	.21
tonight	4	12	48	5	20	.13
would	2	252	504	299	598	.08
your	1	214	214	90	90	.04
yourself	4	12	48	9	36	.04
yourselves	5	< 10	< 50	4	20	.20

words which appeared fewer than ten times. For the sake of consistency, it would seem that many of the present short form words should be dropped, or others added which save as much space as those listed, or both actions should be taken. It is interesting to note, that of the 189 contractions in braille, the twenty-five least effective space savers are short form words.

Ashcroft found that short form words were the most difficult category to read, as is indicated by the error indices in Table VII. He attributed this to two factors. First, many of the short form words occur very infrequently, and often have difficult meanings. Second, those short form words which are frequently used and have common meanings are often so reduced that it is primarily a memory process in order to recognize these words. He recommends that other short form words might be more useful than some of those currently used, and that spellings should not be so abbreviated that recognition becomes difficult.

It seems that many of the short form words are not worth keeping in view of their low space saving and high difficulty. Of the twenty-five contractions which save the least space, all short form words, fifteen are among the twenty-five short form words which had the highest error indices according to Ashcroft and among the sixty most difficult words in all categories. Eleven of the twenty-five

most difficult words in any category are among the twenty-five words which save the least space. In Ashcroft's study each of these words caused difficulty more than one time out of every three which it was encountered. Certainly these contractions detract from the overall reading value of braille. These eleven contractions are: "blind," "conceive," "conceiving," "deceive," "declaring," "oneself," "perceive," "perceiving," "receiving," "rejoice," and "rejoicing." Ashcroft has no data on "deceiving" or it would probably be included in this list also.

The present braille rules say that short form words should be used alone or as parts of words. However, there are numerous restrictions upon their use: they can only be used as whole proper names, cannot result in incorrect spellings, can be used as part words only when they retain their original meaning, and cannot be used if they "would cause confusion in pronunciation or in the recognition of an unusual word. In addition, the short form words for "blind," "after," and "friend" may not be used as parts of words when followed by vowels.

Unfortunately, these rules are not compatible with any but extremely complicated, and therefore, expensive, mechanical translators. These devices cannot determine meaning or pronunciation without having each possible word programmed into their memory. There are two alternative changes of rules

which would greatly simplify this translation problem. Either stop using the short form words as part words at all, which would probably be an aid to reading and of minor concern to space saving, or use them as part words without regard to pronunciation, meaning, or whether they are part of a proper name. The former choice is probably the better. Another solution, less desirable for human translators because it breaks up the rules, but probably better for readers, is to allow some short form words, such as "must," to be used at all times, even in words like "mustache," while restricting most of them to use as whole words. This is most likely the preferable solution, although it does not adhere to the principle otherwise advocated in this study, of consistent use of all words in any given category.

In summary, it is suggested that several of the short form words be dropped. Possible replacements should be considered on the dual basis of their ability to save space and ease of recognition, even to persons not previously familiar with the use of the contractions. Rule 47 should be changed so that most short form words are used only as whole words and that those short form words deemed particularly useful as part words be used without regard to pronunciation, meaning, or other restrictions.

General Rules

Rule 34 governs the general use of contractions and has been a source of conflict since the adoption of Grade II braille in this country. The British who developed Grade II braille have always used contractions without regard to syllabication, except between parts of compound words. In the conference between American and British braille committees the British agreed to a compromise, omitting the use of contractions where they would interfere with legibility or pronunciation. The rule then stated:[23] "Contractions forming parts of words should not be used when they are likely to lead to obscurity in recognition or pronunciation, and therefore, they should not overlap well-defined syllable divisions. Word signs should be used sparingly in the middle of words unless they form distinct syllables. Special care should be taken to avoid undue contraction of words of relatively infrequent occurrence." This rule left a great deal to the judgment of the person embossing braille and lead to large inconsistencies between books embossed by different publishers. The braille committees of both countries issued lists of words as examples of correct application of the rule from time to time, but variations persisted, particularly between the two countries. The forward of English Braille, American Edition, 1959[20] indicates this difference when it says, "A distinct variance

in preferred language usage here in America and in the United Kingdom dictated that braille readers on both sides of the Atlantic could best be served with separate, though basically similar, codes designed to apply to the English language as practiced in each country."

Rule 34 now states, "Contractions forming parts of words should not be used where they obscure the recognition or pronunciation of a word.

a. Contractions may be used:

(1) Where the letters of the contraction are in the same syllable.

(2) Where the letters of the contraction would overlap a minor and/or incidental syllable division.

b. However, a contraction must not be used:

(1) Where the usually braille form of a base word would be altered by the addition of a prefix or suffix. EXCEPTION: The "ea" and the double letter signs "bb," "cc," "dd," "ff," and "gg" should be used even where a word ending or a suffix is added to the base word.

(2) Where it would violate the primary division between a prefix or a suffix and the base word.

(3) Where a primary division occurs between the prefix and the root of a word.

(4) Where base words are joined to form a compound word.

(5) Where the use of contractions would disturb the pronunciation of a digraph or trigraph (two or more letters pronounced as one sound).

(6) Where two adjoining consonants are pronounced separately.

(7) Where the use of a contraction would cause difficulty in pronunciation.

c. GENERAL EXCEPTION: Contractions may be used in such easily read words as: around, arise, arose, acknowledge, baroness, governess, drought, doughty."

No studies have been made of the effect of these rules on the space saving value of the contractions which they govern. It is apparent that these restrictions do cause braille text to take more space, but a considerable amount of text will have to be tested before any quantitative estimate of their effect can be made. The computer program described later in this thesis will aid in such a study by picking out all the possible places that contractions can be used, but manual effort will be required to separate those allowed under the current rules.

The justification of these limitations is that they are supposedly aids to easier reading; the theory being that the braille reader is primarily a syllable by syllable reader and not a word reader. Unfortunately, this theory is out of step with modern educational methods which emphasize recognition of whole word units. Since it is generally felt that finger speed is the limiting factor in braille reading, the restrictions which limit the use of contractions may be felt to slow up reading rather than expedite it as intended. On the subject of systems of contractions, MacKenzie says that the rules governing the use of contractions should be few and

clear. Lochead says, "Once a contraction is decided upon, let it be used always, and not be restricted by a number of petty rules."

Some of the principles which are attempted in the rules cannot be carried out in all cases. For example, contractions are not supposed to be used when they would alter the form of a base word. However, the "com" contraction used in "come" is limited to the beginning of a word, and therefore, must be dropped in the word "income." "squally" is cited as an example of a word in which not to use the contraction for "ally" so that the base is preserved. Yet this same contraction is commonly used in "equally" and "finally."

From the viewpoint of translatability, this rule presents an insurmontable handicap to any device which might be attempted at reasonable expense. Even experienced people occasionally rely upon a dictionary for syllabication, and even dictionaries are not consistent. For instance, the word "everybody" is syllabized "eve-ry-bod-y" in Funk and Wagnall's New Standard Dictionary,(7) whereas it is "ev-er-y-bod-y" in Webster's New International Dictionary, second edition.(13) Even more difficult is interpretation of the general exception because there is no standard as to what constitutes an easily read word.

In summary, it would appear that when all three of the previously discussed criteria: space saving, readability,

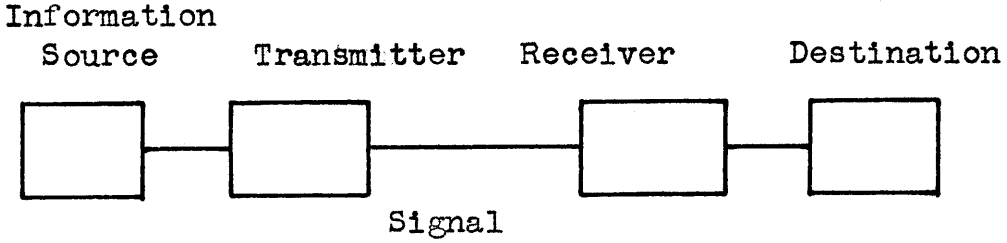
and translatability, are taken into consideration, that it is desirable to change Rule 34 to allow the use of contractions wherever they may occur in a word.

Some Comments on the Efficiency of Braille

So far in this thesis, the number of characters saved per 100,000 words has been used as a measure of space saving. This is a convenient figure since it is easy to calculate once the occurrences of words or contractions have been counted. Also, it is quite satisfactory for the comparison of the contractions to see which are most effective in reducing the space required by braille and which are superfluous and save little space. The number of characters saved per 100,000 words is not, however, a good measure for the evaluation of the entire system. Certainly a much larger number of characters could be saved by the addition of more contractions, further reduction of short form words, and assigning multiple meanings to more characters, but if this were done the value of braille as a means of communication might be destroyed. Therefore, some better means of overall evaluation is needed to judge the efficiency of braille.

The mathematical theory of communication offers a means of converting the raw data into a figure of merit which can be applied in judging the present braille system and suggested revisions of it. Any communication system consists of several

elements which have general names as shown in the diagram below:



These elements are given specific names when a particular communication system is considered. In the case of braille, the information source is a book to be translated, or an idea in the mind of some individual; the transmitter consists of the process of translation into braille and the actual embossing on paper. The receiver is the fingers and mind of the reader who changes the braille signal back into the message for his mind, which is the destination. The part of this system of primary interest here is the signal and the channel carrying this signal, the embossed braille. The system which braille will be compared to is printed English, wherein typewriters or printing presses take the place of braillewriters or slates, eyes the place of fingers, and the channel which carries the signal corresponds to a printed page.

The basic unit of information is the bit, a name shortened from binary digit. One bit of information is that amount of information which is determined when a choice is made between two possible messages, such as 0 and 1,

yes and no, or the presence or absence of a raised dot in one position of a braille cell. Two independent sets of two choices each would contain two bits of information. This combination could give four possible messages. For example, suppose one choice is 0 or 1, and the other A or B, then the possible messages are 0A, 0B, 1A, and 1B. Extension of this reasoning shows that N bits of information allow 2^N possible messages. Inversely, M possible messages are uniquely determined by the logarithm of M to the base two bits of information is:

$$I \text{ (number of bits)} = \log_2 M \text{ (number of different possible messages)}$$

The English alphabet contains twenty-six letters, so:

$$\log_2 26 = 4.7$$

Therefore, each letter could transmit a maximum of 4.7 bits of information.[11] This figure represents the amount of information which could be transmitted if our language were structured such that any letter was equally likely to occur at any time. However, the structure of English reduces the amount of information. For example, the "u" after "q" transmits no information, because everyone knows that "q" in any word is followed by "u." Just the different frequencies of letter usage reduce the maximum information content to 4.14 bits per letter.[11] There are also other reductions based on the probabilities that one letter will follow another, for instance, "e" often follows "th" forming the word "the."

Furthermore, there are long range effects which reach over hundreds of words. This effect was mentioned earlier when the I.B.M. 704 braille translation program was described. The program is revised slightly after testing a sample of each book or author, and this generally adjusts the program to each writer's vocabulary.

Shannon[33] conducted experiments in which people guessed the next letter of a particular passage. If they guessed wrong, the correct letter was supplied; right or wrong they then proceded to the next letter. The number of corrected letters supplied by the examiner was used to measure the information actually transmitted. It was assumed that letters which were correctly guessed contained no information. Using this data Shannon calculated the maximum information content of English to be about 1.6 bits per letter.

It should be noted that apparently none of these calculations considered the effect of punctuation. These marks are obviously necessary to transmit information in some cases, such as in these sentences:

The professor said, "The dean is ignorant."

"The professor," said the dean, "is ignorant."

These marks also increase the maximum information per character, so no conclusions can be drawn of their effect on the overall average information content per character.

Since English contains only 1.6 out of a possible 4.7

bits of information per letter, it has a relative information content, or a relative entropy, of:

$$\frac{1.6}{4.7} = 34\ \%$$

Redundancy is defined as one minus the relative entropy, ie. English is 66% redundant according to Shannon's experiment. It should be possible to transmit the same amount of information using the same alphabet but 66% fewer characters.

Since each dot of a braille cell can transmit one bit of information, each cell contains a maximum of six bits of information. If braille obtained the maximum reduction of English text, it would reduce it by:

$$1 - \frac{1.6}{6} = 73\ \%$$

Using the data in Tables I through VII on the space saving of the individual braille contractions, Grade II braille would save a total of 116,320 characters per 100,000 words. The average length of a word in English is 4.5 letters. Therefore, braille reduces English text by approximately 26% since:

$$\frac{\text{characters saved}}{\text{total characters}} = \frac{116,320}{4.5 \times 100,000} = 26\ \%$$

This means that the text is reduced by a little over one-third of the maximum possible reduction. While the structure of English prevents realization of the maximum reduction, a study of this structure would aid in approaching this maximum. For instance, Dewey[4] states that the nine

most common words comprise about 25% of the words used in writing English. Frequently occurring words are more easily recognized when only some of their letters are retained; therefore, these words contribute more to the redundancy of English, and they offer the greatest area for lessening this redundancy in braille. By shortening all of these words to one character, a great deal of space is saved. However, insignificant amounts of space are saved in words which occur very seldomly. If the primary space saving effects of braille are achieved by decreasing the redundancy, then there should be little added difficulty in the reading of braille. For example, of the fifty most common words in English, twenty-nine are already among the 189 braille contractions, and seventeen more require only two braille characters. Of the remaining four, the following contractions should be formed: "al" for "all," which requires that the current short form of "also" be changed to "als," thus making it easier to recognize this word; "hz" or "hs" could be used for "has;" and "wht" for "what." It would be difficult to reduce the last word, "been," without confusing it with "ben" or violating the rule concerning lower contractions. The addition of these three contractions would save more space than the twenty-six least efficient contractions now used. It is apparent that by studying the redundancy of English further, more useful, easily recognized contractions could be formed to replace the

inefficient ones now in use. Studies, such as those by Paul Ebert,[29] should be conducted to find which frequent part word letter sequences are not contracted now.

Table VIII, which lists the current contractions in order of decreasing space saving as shown in Tables I through VII, and Figure I, which shows this data graphically, indicate the wide variation among the current contractions. The solid line shows the cumulative total of space saved by the contraction to the left of any point on the line. The slope of the line indicates the decreasing value of the contractions. For example, half of the total space saved is saved by fifteen of the 189 contractions, and eighty contractions, less than half, save 90% of all the space economized. The use of more frequent contractions can reduce the redundancy inherent in English without making reading more difficult since tests such as Shannon's have shown that many letters are unnecessary to understanding, even when no consistent rule is applied to their use or omission.

It should also be pointed out that dropping many of the present contractions and replacing them with fewer, but more frequent contractions, will probably make it easier for blind people to read and most certainly reduce the problems of teaching braille reading. In addition, such changes would make the design of a mechanical translator easier and less expensive because not as many contractions would have to be sought and checked for correctness by the machine.

TABLE VIII

BRAILLE CONTRACTIONS IN DECREASING ORDER OF SPACE SAVED

the	7650	gh	705	good	244
and	7570	some	688	should	236
to	5848	one	633	ence	235
in	4284	more	630	after	224
er	4008	were	610	those	224
of	3998	would	598	right	222
ed	3943	him	540	ff	219
en	3344	ance	534	between	216
ing	2826	dis	528	your	214
st	2769	into	498	its	208
that	2690	ness	498	many	208
for	2486	said	484	out	203
th	2469	about	470	do	203
ar	2458	because	432	again	192
ea	1939	before	417	ally	190
with	1860	ble	405	day	190
have	1851	time	404	through	186
was	1678	them-		part	182
ou	1633	selves	396	still	174
will	1335	can	394	word	174
ation	1323	there	384	ought	174
from	1299	every	374	less	172
ow	1219	himself	364	today	170
it	1216	shall	360	neces-	
by	1200	like	339	sary	165
not	1178	ity	325	must	163
sh	1146	know	323	young	160
this	1144	ever	318	where	159
ch	1098	upon	306	perhaps	156
wh	1084	under	304	after-	
his	1034	so	300	noon	155
but	1008	sion	296	work	154
tion	1000	could	292	against	146
can	964	very	290	itself	144
which	908	ong	276	ful	142
be	846	their	273	cc	141
had	844	ound	266	also	140
people	815	ment	266	these	139
com	790	always	264	great	134
as	782	first	262	such	132
you	775	just	254	us	123
little	728	cannot	248	know-	
				ledge	120

TABLE VIII CONTINUED

character	116	tomorrow	55
dd	112	lord	54
quite	108	friend	51
letter	108	above	50
much	104	tonight	48
world	102	mother	48
almost	102	yourself	48
spirit	100	bb	47
receive	100	across	42
myself	99	although	36
beyond	99	herself	33
rather	96	afterward	32
father	96	paid	32
question	92	deceive	32
name	90	declare	30
enough	88	beside	30
ount	87	perceive	30
immediate	84	quick	30
o'clock	84	rejoice	24
here	82	blind	20
ourselves	80	yourselves	20
already	75	beneath	18
together	75	conceive	15
go	73	thyself	15
child	72	receiving	12
either	72	below	9
gg	71	rejoicing	3
whose	70	perceiving	2
children	70	braille	0
according	68	conceiving	0
behind	68	deceiving	0
altogether	65	declaring	0
neither	64	oneself	0

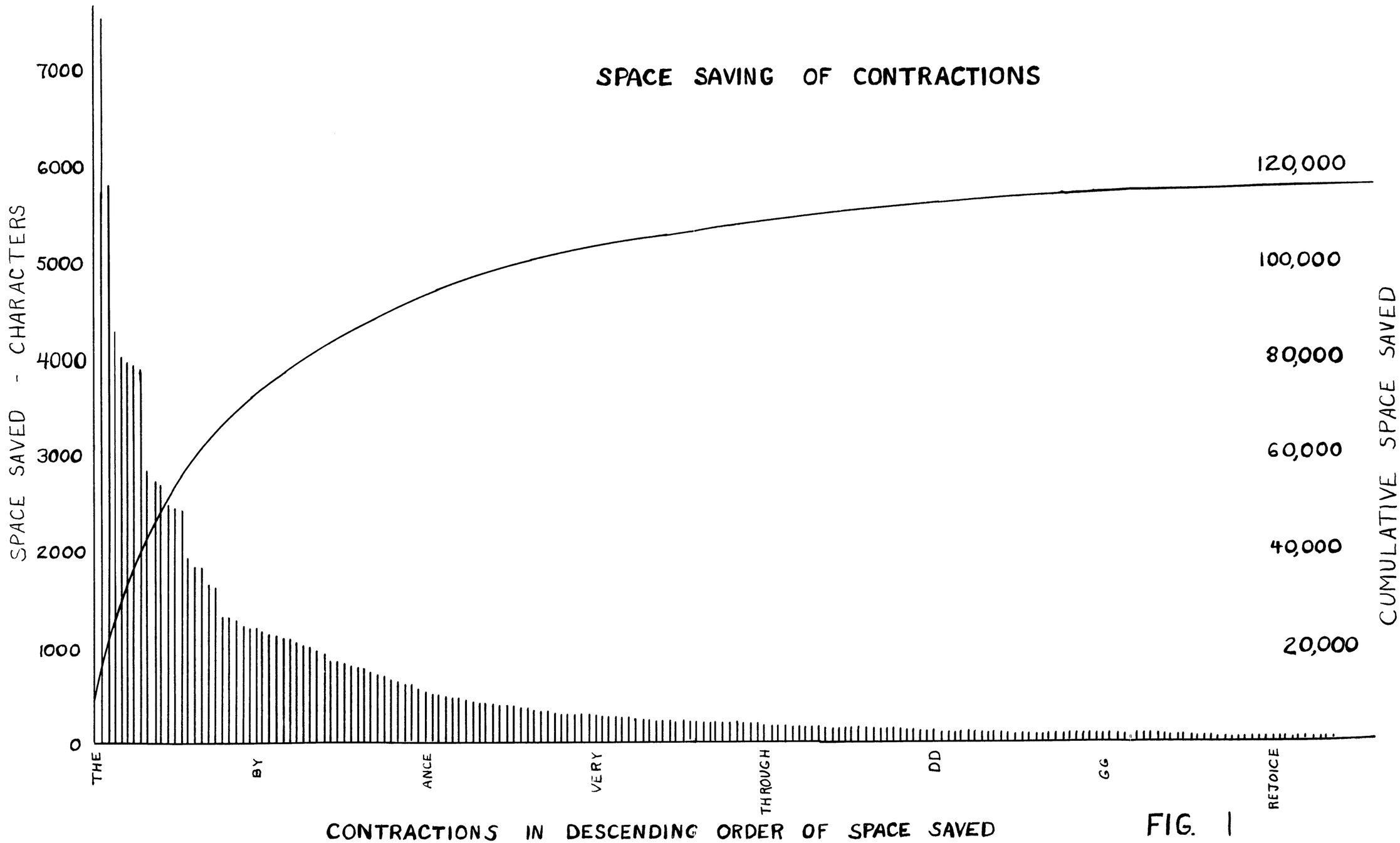

SPACE SAVING OF CONTRACTIONS
SPACE SAVED - CHARACTERS
7000
6000
5000
4000
3000
2000
1000
0
120,000
100,000
80,000
60,000
40,000
20,000
CUMULATIVE SPACE SAVED
THE
BY
ANCE
VERY
THROUGH
DD
GG
REJOICE
CONTRACTIONS IN DESCENDING ORDER OF SPACE SAVED

FIG. 1

Summary of Recommendations

It was suggested that consideration be given to the following changes of contractions:

1. "g" to represent "great" instead of "go."
2. "r" to represent "right" instead of "rather."
3. Discontinue the use of a single cell contraction for "enough."
4. Stop using the double letter contractions "bb," "cc," "dd," "ff," and "gg."
5. Eliminate use of the initial letter contractions "mother," "father," "lord," "spirit," "name," "world," "character," and "whose."
6. Discontinue use of the short form words "oneself," "declaring," "deceiving," "conceiving," "receiving," "perceiving," "rejoicing," "below," "yourselves," "thyself," "conceive," "beneath," "blind," "rejoice," "deceive," "perceive," "declare," "afterwards."
7. Add contractions "al" for "all," "hz" or "hs" for "has," and "wht" for "what."
8. Change the contraction for "also" from "al" to "als."

Furthermore, each contraction, particularly short form words, initial and final letter contractions, and lower contractions, should be thoroughly studied with reference

to ease of reading and space saving. New contractions should be devised for those words among the one or two hundred most common words which are currently spelled out in full, and which have obvious contractions which would not impair reading.

It is also suggested that the following rules concerning the use of contractions be changed so that the rules are consistent with themselves and with the capabilities of mechanical translators.

Rule 34. Amend so that contractions are used when the sequence of letters they represent appears in a word, regardless of pronunciation or syllables.

Rule 36 b. Revise so that the alphabetic and similar whole word contractions are permitted before the apostrophe in all words, even colloquial ones.

Rule 37. Revise so that space is omitted between "a," "and," "for," "of," "the," and "with" at all times, except when they are separated by punctuation.

Rule 41. Revise so that the contractions are always used for, and the space omitted after, "to," "into," and "by" except when they are followed by punctuation.

Rule 42 b. Omit this section, thereby allowing double

letter contractions and "ea" to be used whenever they occur in the middle of a word.

Rule 43. Revise so that "be," "con," and "dis" can be used whenever they appear at the beginning of a word and not just as the first syllable.

Rule 45. Revise so that punctuation is not considered in using the initial letter contractions as part words.

Rule 45 a. c. d. Eliminate these three sections so that "one," "some," and "part" may be used as part words at all times without regard to syllabication.

Rule 46 b. c. Omit these sections so that "ness," "ity," and "ally" can be used at all times.

Rule 47. Amend so that short form words are used as part words wherever they appear, or so that some are used as part words all the time and others are not used at all.

READING TESTS OF SOME OF THE RECOMMENDED REVISIONS

Many of the recommendations in the preceding chapter may be summarized by saying that the use of contractions may be limited by position in a word, but otherwise a contraction should be used whenever the appropriate sequence of letters occurs without regard to syllabication or punctuation. As was pointed out in the section on history, British usage based on this point is different than American, for the British hold much more to a rule of sequence with some exceptions, while the Americans apply a rule of syllabication with a few exceptions. Therefore, a large group of braille readers are already subject to some of the proposed changes, apparently with no determent to their reading ability.

A preliminary investigation was made of the effect of the revised rules on the ability of American blind people to read brailles. The changes tested were:

(1) use of the contraction "be" when it appears at the beginning of a word, but is not the first syllable,

(2) changing the form of a base word when a prefix or suffix is added,

(3) use of initial letter contractions as part words when their pronunciation is changed,

(4) allowing contractions to overlap a primary division

between a base word and its prefix, and

(5) allowing contractions to overlap the primary syllable division between parts of a compound word.

In deciding on test words, the words "really" and "equally" were used as examples where the "ally" contraction should not be employed because the braille form of the base words "real" and "equal" would be altered. Such use is prohibited by Rule 34. b. (1) and the word "squally" is cited as an example. However, Rule 46. c. specifically prohibits the use of the contraction only when "y" has been added to a base word, and "really" is cited as an example of correct use of the contraction. The revisions suggested in the preceding section would correct the misleading effect of Rule 34. b. (1), or the inconsistency of interpretation, whichever the case is, by consistantly allowing the use of "ally" in all words.

Two paragraphs were written which contained the following words:

(1) Examples of "be" contracted when not a syllable in "best," "beets," "beckons," "better," "beefy," and "bellowing."

(2) Words where the base word was changed after the addition of a prefix or suffix, "uneasy," "really," "equally," and "unfulfilled."

(3) Words using initial letter contractions when the pronunciation was changed, "severe, "sphere," and

"feverishly." The initial letter contraction "part" was used in "partaken" where it is specifically prohibited by the rules.

(4) Contractions which overlapped primary syllable divisions between prefixes and suffixes in the words "erection," "changeable," and "prediction."

(5) Contractions which overlapped the division in the compound words "pineapple," and "painstaking."

Each of the two paragraphs which were prepared to test these changes contained ten of the above words. Text material for the paragraphs was condensed and paraphrased from current issued of Time and the Reader's Digest. A list of ten words, five from each paragraph was prepared to be read by each subject before the paragraphs were read. The list and paragraph combinations were embossed twice, once in correct braille, and once using the revised rules in the words where they were applicable.

The test subjects were requested to read one paragraph in standard braille and the other in revised braille. Errors and hesitations as well as the time required to read each paragraph were recorded on separate forms for every subject. Appendix D contains a copy of the form used in these tests.

Since this was intended as merely a preliminary check, and subjects were difficult to contact during the summer vacation season, only twelve subjects were tested. Most of

these were instructors of the blind, as well as being blind themselves. Their ability to read braille ranged widely, depending on how long they had relied upon it. Some had been blind since childhood and knew no other means of reading except braille, while others had become blind as adults and only learned to read braille in the last year or two. When further tests are made, it is recommended that school children be included so that the complete range of braille readers can be checked.

The paragraphs using revised spelling required an average of 12% more time to read than their standard counterparts. However, much of this difference must be attributed to the time taken by subjects to comment on revisions even though they were asked to save comments until after they had finished reading. The few cases where subjects did not comment resulted in time differences of less than 6%, with two subjects favoring the revised paragraphs and two subjects favoring the standard paragraphs. The individual times and the number of hesitations and errors for each paragraph are recorded in Table IX.

Only two words were read incorrectly in the revised paragraphs. "Unfulfilled" was twice read as "unbelieved," probably because the contraction for "ful," dots 5-6, 1, was mistaken for dots 2-3, 1, which is the contraction for "be" followed by "l," even though the "be" contraction was never used in the middle of a word. The error was not realized

TABLE IX

SUMMARY OF READING TEST

	Standard			Revised			
S.	W.L.H.	P.H.	P.T.	W.L.H.	P.E.	P.H.	P.T.
1	0	0	1:15	5	1	1	1:40
2	0	0	1:10	0	1	2	1:25
3	0	0	5:20	0	0	2	11:50
4	1	0	1:50	2	1	2	1:20
5	2	1	1:40	2	0	1	1:55
6	3	0	2:10	3	0	3	2:45
7	1	0	1:50	3	0	0	1:55
8	0	0	3:50	3	0	2	3:35
9	0	2	1:30	2	0	0	1:25
10	0	0	2:45	0	0	2	3:00
11	0	1	2:30	5	0	3	2:50
12	0	4	2:55	0	0	2	3:05

S. = Subject

W.L.H. = Word list hesitations

P.H. = Paragraph hesitations

P.T. = Paragraph time

P.E. = Paragraph errors

because either word would fit adequately into the context of the sentence. The word "predication," meaning assertion, was substituted by one person for "prediction," probably because the person was trying to keep the "ed" contraction in one syllable. It should further be pointed out that either word fits perfectly into the context of the entire paragraph, and that confusion often results between the final letter contractions for "sion," "tion," and "ation."

The revised words caused twenty-five hesitations out of 120 encounters in lists for an error index of .21, while the standard words caused seven hesitations for an error index of .06. In the paragraphs, standard words caused eight hesitations out of 120 encounters for an error index of .07, while the revised words caused twenty-one hesitations which combined with three errors gives a total error index of .20. It should be remembered that these errors were primarily hesitations, some of which were very minor, so that all the error indices indicate a great deal more difficulty than is really the case.

After reading, the subjects were asked for any comments which they might have on the proposed changes. Seven of the twelve said that they felt the changes would not slow them down or cause them any trouble if they became the standard, since they would quickly become accustomed to them even though they looked a little strange now. Three people further commented that there are many mistakes found in braille printing

and that therefore, some of the changes should cause no problems and might not even be noticed.

Two things are offered in support of these last comments by the subjects. First, two or three unintentional mistakes were made in embossing the pages used for the reading tests. About one-third of the people hesitated on the mistakes, and only half of those were aware that mistakes had been made. Second, many people reported that they had seen some of the words in books, embossed in the incorrect, or revised, form used in the tests. Among these words were "pineapple," "uneasy," "squally," "changeable," and "unfulfilled." Also, a few people said that in writing their own notes they used some of the contractions in the revised manner. Some commented that since the slate was still in widespread usage for taking notes, any revisions which saved space were highly desirable.

A summary of the test results would indicate that, while more study is necessary, the changes proposed in this thesis generally would not add a burden to reading after they became accepted as standard. The question of how to teach braille and correct spelling to blind children is one which has already been raised frequently and will continue to exist whether these changes are adopted or not.

7090 COMPUTER PROGRAM FOR FINDING BRAILLE CONTRACTIONS

At the present time adequate data is lacking on the frequency of braille contractions. The Irwin and Wilcox[19] study does not cover some of the newly added contractions, and also leaves much to be desired in the range of material sampled. Word counts, such as Dewey's[4] and others are not adequate except for those contractions which are used only as whole words. For these reasons, it would be desirable to conduct a frequency count of the current contractions in a wide range of material.

Furthermore, it would be advisable to count the number of times which the revisions suggested in this thesis would effect braille. In this way, their space saving could be calculated and some idea obtained of how often a reader may be bothered by them. Also, it would be advantageous to have some means of measuring the frequency of any proposed new contractions.

While it is possible to do this counting by manual methods, it is a time consuming task, which also presents the opportunity for inaccuracies, since the human eye and mind have a tendency to miss some such letter sequences when scanning a page. Therefore, it seemed desirable to write a computer program to search text for braille contractions. Once written, the program would save a great deal of time in

any such counting and, if each contraction is searched for separately, new contractions could be counted easily with very little additional work.

Computers are capable of performing simple mathematical or logical operations quite rapidly. By combining sequences of these operations, they are able to do large amounts of repetitive calculations in short periods of time. Often in mathematical problems, these repetitive operations can obtain numerical solutions to problems which could not be solved otherwise. In order to perform these tasks, a computer must be instructed precisely what to do, and each operation must be ordered in the proper sequence. A program is a set of instructions which tell a computer what to do. In order to make the programming of particular problems easier, general programs have been developed which take one instruction written in the special program language and change it into a series of elementary steps in the language of the electronic computer. Without these general programs, only highly trained people could write instructions for computers.

The machine translation group at M.I.T. has developed a programming language named COMIT[15] [16] which is especially well suited to linguistic work of any kind. The COMIT system was selected as the means of writing the braille contraction search program. In addition, the machine translation group has available large quantities of English text selected from

newspapers, literature, and patents. This material provides a source of text samples which are already prepared for computer use on punched cards or magnetic tape.

The major part of the search program consists of a number of independent sections. Each section searches the sample text for a particular sequence of letters. In the computer each letter is a separate element; words are distinguished by the spaces between them. When using COMIT these spaces are represented in the computer by hyphens, and the hyphens have special symbols to distinguish them from spaces. In order to specify the position of a contraction in a word, the hyphens are also used in the sequence. For example, the contraction "be" is used only as a whole word or at the beginning of a word. Therefore, the computer is instructed to search for the sequence "-be." Wherever such a sequence is found the computer increases a counter by one and also prints the sequence plus everything following it up to the next space. At the end of the text, the computer prints out the total count and then is ready for instructions to search for a new sequence.

The printout of each word containing a contraction is used to correct the total count, since a word such as "wither" would appear under four contractions, "with," "the," "th," and "er." Only the "with" and "er" contractions are used, however, and the counts for the "the" and "th" would have to

be corrected. It is easier to correct the counter manually than to write a computer program which would allow for all such contraction overlaps. Also, the information gained by checking for overlaps gives a better estimate of the effect of adding or omitting contractions. For instance, the sequence "ear" occurs in many words. The "ar" contraction is used in preference to the "ea." If the "ar" contraction were to be no longer used (an example, not a suggestion) it would make no difference in the length of words with "ear" and therefore, these should not be counted in evaluating the effect of such a change on space saving.

Printing out each word also allows easy counting of the times when a contraction is currently not used because of syllabication. This number can then be used to evaluate the space saving of such changes, the number of times a reader is likely to encounter them, and the relative frequency of different words affected by the removal of syllabication rules. This last information is useful because, regardless of rules concerning syllabication, some words will probably be easily recognized while others may be more serious reading problems. A study of particular words in relation to their frequencies is a much fairer way to evaluate changes than merely to cite examples of words that are easy or hard to recognize from memory.

Any number of contractions can be counted in one

computer run by the addition or deletion of the independent sections for each contraction. The other portions of the program control computer input operations and adjust the format of the input to the braille search program.

Most of the search, printout, and counting operations are performed by one rule for each contraction. A second rule prints the total number and returns all elements to their original state in preparation for the next independent contraction search. Originally it was planned to have the computer search for sequences, such as the following example for "and;" an indefinite number of unknown elements is indicated by"$" in this search:

- + $ + A + N + D + $ + -

In this manner, the sequence "and" and everything surrounding it, from the space preceding it to the space following it, was to be picked out. The computer, however, picked out the first available space rather than the space immediately preceding the sequence "and." This led to mechanical problems which made running the program impractical and often impossible.

There was no apparent way to distinguish the space immediately preceding a contraction without slowing the search process considerably. Therefore, it was decided to record a spacific number of characters preceding the contraction. Thus, when a contraction is found, the twenty-five

characters preceding it are printed, regardless of what they are, as well as all the characters following the contraction up to the next space. After a contraction is found, the material to be printed is duplicated in the workspace. The copy is then used for printout on the usual computer output monitor tape and the original is maintained in the workspace for further search. Material preceding the twenty-fifth character before the last sequence which has been found is queued on a shelf. A running count of occurrences is recorded as the subscript on a special marker.

After all the text in the computer workspace has been searched and queued, the number of occurrences is printed out, the marker subscript is returned to zero, and the shelved material is returned. The computer then starts a search for the next contraction.

The amount of material in the computer workspace is limited by the size of the core memory; in the case of the I.B.M. 7090 it is approximately 120 cards or about 1,350 English words. Since it is usually desirable to search more material, the amount which the computer will read at one time is controlled to prevent overflowing the workspace. After the material read in one workspace limit has been searched for all contractions, it is replaced by the next section of text. A complete accounting of the program which was used in the final test runs will be found in Appendix E.

Several difficulties other than normal programming problems were encountered in obtaining results from the program. Among other things, the computer failed to read the magnetic tapes containing sample texts on three successive runs. This was apparently due to the decay of the tapes, which are several years old. Until the old tapes can be replaced, it is necessary to use punched card input. Unfortunately, most of the punched cards available in a suitable format were copies of United States Patents. A comparatively small sample of about 7,000 words was taken from the patents available as a test program. The results of this test are listed in Table X. However, it should be pointed out that programming a computer to search for the contractions is not effecient for a sample of this size. Dr. Yngve[37] suggested that the break-even point between computer and manual search techniques was probably somewhere between 10,000 and 20,000 words sampled. In the future, much larger samples will be tested when the present tapes are in order or when new samples are punched. It is comparatively easy to prepare any desired text for searching, so that reading material peculiar to the blind may be considered in evaluating contractions also.

It can be seen that the results of this test are in quite reasonable agreement with previous data as cited

earlier in this thesis, particularly considering the small sample size and the technical nature of patent texts.

TABLE X

RESULTS OF COMPUTER SEARCH

Contraction	Occurrences In Sample	Occurrences Per 100,000 Words	Irwin and Wilcox
and	366	4,575	3,785
for	43	537	1,243
of	254	3,175	3,521
the	830	10,380	7,650
with	44	500	930
in	426	5,320	4,284
ar	193	2,290	2,458
ch	108	1,350	1,098
ed	272	3,400	3,943
en	305	3,810	3,344
er	362	4,508	4,008
gh	33	425	705
ou	120	1,500	1,633
ow	99	1,240	1,219
sh	124	1,550	1,146
st	208	2,600	2,769
th	219	2,740	2,469
wh	137	1,095	1,084
ally	9	113	190
ance	20	250	267
ation	37	462	441

TABLE X CONTINUED

Contraction	Occurrences In Sample	Occurrences Per 100,000 Words	Irwin and Wilcox
ence	22	275	235
ful	12	150	142
ity	21	262	325
less	4	50	86
ment	24	300	266
ness	6	75	49
ound	15	188	266
ount	6	75	87
sion	11	136	148
tion	48	600	500
ong	19	238	276
ble	28	350	405
ing	247	3,085	2,826
bb	3	38	47
cc	12	150	141
dd	11	135	112
ea	167	2,087	1,939
ff	11	137	219
gg	6	75	71
be	63	786	801
com	30	375	395
con	128	1,600	482
dis	13	163	264

CONCLUSION AND RECOMMENDATIONS

The purpose of this thesis has been to analyze Grade II braille and recommend those changes which would be necessary to allow machine translation from ink-print to braille. The recommendations are based on a translator which would be of economical size and a feasible cost. Thus it is not possible for this translator to have a special record of every word, or even the words where contractions are currently restricted by rules other than those which are easily defined in terms of letter and other symbol sequences. Also indicated in the analysis are such factors as the space saving effect of various contractions and their influence upon the readability of braille.

The history of braille and other forms of raised printing for the blind in this country indicates that the objective approach which the Uniform Type Committee took up in the 1930's needs to be revived again. This approach enabled the early committees to sponsor major studies of the readability and other features of various systems. The desire for world uniformity and the resistance of the British to change has, in recent years, lead to a more emotional and less scientific basis for the standards of braille. Unfortunately, this change of approach has still not achieved the desired uniformity.

This study has repeated the findings of other studies, in that some of the current braille contractions are not achieving the primary purpose of contractions, that of saving space, both to reduce the bulk of books and to make reading more rapid. It has further applied some of the ideas of the mathematical theory of communication and the abilities of the high speed electronic computer to the task of accurately selecting the least worthwhile contractions and of finding more practical ones with which they may be replaced.

The entire set of braille contractions has been divided into logical categories and the contractions in each of these categories have been evaluated on three points: space saving, readability, and translatability. From this analysis recommendations have been made to eliminate several current contractions and change the rules concerning the use of other contractions. These recommendations may be summarized by saying eliminate all infrequently used contractions and omit rules concerning syllabication and pronunciation. It is felt that these changes will increase the value of braille for several reasons. First, by simplifying the rules and dropping the infrequent and difficult contractions, many people will learn braille, and others who already know it will find more use for braille because they will not be discouraged by its current complexity. Second, allowing for mechanical trans-

lation improves the possibility of making available newspapers and a much wider range of books and magazines to the blind without long delays for translation. In addition, these materials will be produced at a lower cost. Third, by eliminating many of the current contractions which save very little space, it will become easier to adopt a few new contractions which would save much more space and actually be an aid to reading.

This thesis should present some form of basis for further study in various directions. First, from the ideas of information should come some research to find those parts of our language, primarily frequent words and part word letter combinations, which are the major contributors to the high redundancy of English. An analysis of these words and parts of words should then be made, considering their effect on space saving changes as determined from the results of the braille search computer program, their effect on readability as determined by reading tests based on words selected as typical from the search program and weighted by frequency, and their ability to be easily assimilated into a translating machine.

Another area for study is that of an actual translating machine based on the revised braille rules suggested in this thesis. This should include not only design, but actual construction and testing of the device. The operation of such

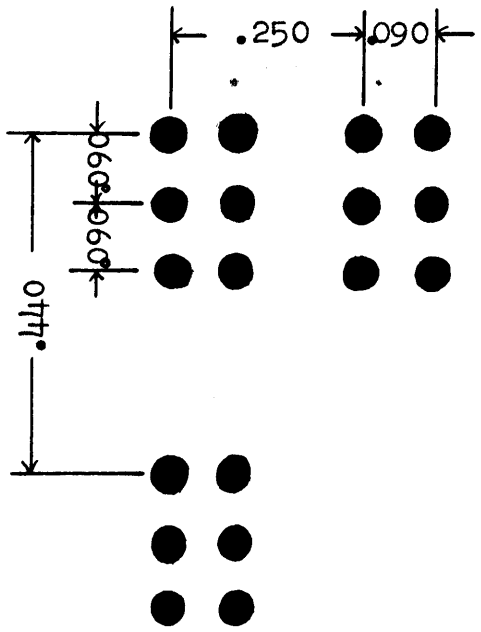
a device should serve as a strong impetus to the overall revision and improvement of braille.

Finally, it is hoped that consideration of this and other changes in braille will not be stifled by the prejudices of those sighted people who have devoted a great deal of time to the blind. The blind people who must use braille everyday as their primary means of written communication should be the judges of what is best for them. The requests and suggestions of these people concerning the availability of reading material originated the interest in this study and the comments of other blind people, particularly those who assisted in the reading tests, have encouraged this author to believe that many of the blind desire to have braille improved and are especially willing to accept any changes necessary to make a larger quantity of more varied braille material available.

Appendix A

A Full List of the Use of Braille Symbols and Contractions

The basic braille form is a 3x2 matrix with raised dots at any of the six points. Normal dimensions of the cells, their spacing in lines, and the spacing between lines are shown in the figure below. While the dimensions shown are fairly standard, they may vary by one or two thousandths of an inch, depending upon the custom of a particular publisher.



In assigning letter values to the available characters Louis Braille arranged the possible dot combinations into seven lines. His systematic grouping of the cells and his

assignment of letters are still used whenever Roman letters are the means of writing.

The first line is composed of dots 1,2,4, and 5. Line two consists of the characters in line one with dot 3 added. The addition of dots 3 and 6 to the first line gives the characters of line three. Line four is formed by adding dot 6 to the characters in line one. Line five uses dots 2,3,5, and 6 to form the characters of line one in the lower part of the cell. Each of the preceeding lines has ten characters. Line six uses dots 3,4,5, and 6 to form six characters, and line seven uses the right half of the cell, dots 4,5, and 6, to form seven characters. These seven lines total sixty-three characters, and with the space account for all sixty-four combinations available from the $3^{x}2$ matrix.

Lines one, two, and the first half of line three were assigned to the alphabet by Braille. (The French alphabet has no "w.") All except "a," "i," and "o," have also been assigned contractions which may be used as whole words only, since the reader is able to easily distinguish when the characters touching only spaces or punctuation are used. Line one has also been assigned to the numbers; the use of numbers is indicated by a number sign embossed before the number in braille.

Line One

	a		1
	b	but	2
	c	can	3
	d	do	4
	e	every	5
	f	from	6
	g	go	7
	h	have	8
	i		9
	j	just	0

Line Two

	k	knowledge
	l	like
	m	more
	n	not
	o	
	p	people
	q	quite
	r	rather
	s	so
	t	that

Line Three


u us


v very


x it (mnemonic device used to remember "exit.")


y you


z as

The remaining five characters of line three are assigned to frequently used letter combinations and are used whenever those combinations appear as either whole words or part words with few exceptions.


and


for


of


the


with

Line four is used for nine more common letter combinations and the letter "w." Six of these characters also represent whole words when written separately from the letters or contractions.

Line Four


ch child


gh


sh shall

th	this
wh	which
ed	
er	
ou	out
ow	
w	will

The characters in line five are assigned multiple meanings. They are used for punctuation and one or two contractions as well. The reader relies upon rules concerning position in word and context to tell him which meaning to use. As a mnemonic device these characters are sometimes named by their corresponding first line characters; these names are included in parentheses.

Line Five

,	(comma)	
;	(semi-colon)	be
:	(colon) *	con
.	(period)	dis /
		enough #
!	(exclamation)	to
()	(parentheses)	were
"?	(opening double quote, question mark)	his
		in
"	(closing double quote)	was, by

ea	(lower a)
bb	(lower b)
cc	(lower c)
dd	(lower d)
en	(lower e)
ff	(lower f)
gg	(lower g)
	(lower h)
	(lower i)
	(lower j)

*Used at the beginning of a word only.
#Used as an entire word only.
/Must never be used to begin or end a word.

Line six is used to form seven more contractions, three three marks of punctuation, and the number sign used to distinguish the use of characters from line one.

Line Six

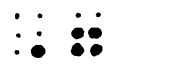
	/ (bar, fraction line)	st	still
		ing	
	# (number sign)	ble	
		ar	
	' (apostrophe)		
	- (hyphen)	com	the letter c lowered two positions

Line seven is used to indicate various changes in composition.

Line Seven

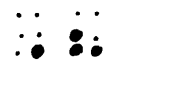
	accent sign	(used before a letter which is accented in ink-print)
		
		
		(These signs are used in forming two-cell contractions.)
	decimal point and italic sign	(used to indicate a decimal point or an italicized word)
	letter sign	(used to indicate that a single letter is intended and not an alphabetic contraction)
	capital sign	(used to indicate a capitalized letter)

In addition to the above characters, some marks of punctuation are indicated by two braille characters.

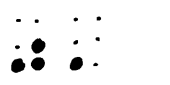


[opening bracket (parenthesis preceded by dot 6)

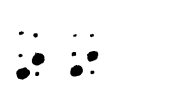
] closing bracket (parenthesis preceded by dot 3)



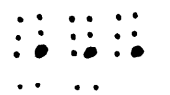
‘ opening single quote (dot 6, opening double quote)



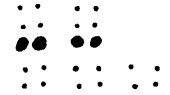
’ closing single quote (closing double quote, dot 3)



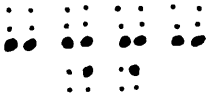
* asterisk



... ellipses



— dash



—— long dash

double italic sign (used before three or more italicized words; its effect is ended by a single italic sign preceding the last italicized word)

double capital sign (used before a capitalized word)

termination sign (used to terminate capitals or italics in the middle of words)

Also, several words and letter groupings have two cell contractions. Some of these, called initial letter contractions, are formed by preceding their initial letters with one of three characters from line seven.

Dot Five Initial Letter Contractions:

day	ever	father	here
know	lord	mother	name
one	part	question	right
some	time	under	work
young	there	character	through
where	ought		

Underlined segments indicate that the second character is the contraction for the underlined letters, not the initial letter.

Dots Four and Five Initial Letter Contractions:

upon	word	these	those	whose

Dots Four, Five, and Six Initial Letter Contractions:

had	many	spirit	world	their

Final letter contractions use signs from line seven and the final letter of the contraction. These contractions may not be used at the beginning of words, because their final cells are also used for composition signs.

Dot Four and Six Final Letter Contractions:

ound	ance	sion	less	ount

Dot Five and Six Final Letter Contractions:

ence ment	ong ity	ful	tion	ness

Dot Six Final Letter Contractions:

ation	ally

In addition to the above, there are seventy-six words which are written in abbreviated form and usually referred to as short-form words. These short forms may also be used as parts of words, provided that their original pronunciation and meaning is retained and no errors in spelling are introduced.

Short-Form Words

ab	about	beh	behind
abv	above	bel	below
ac	according	ben	beneath
acr	across	bes	beside
af	after	bet	between
afn	afternoon	bey	beyond
afw	afterward	bl	blind
ag	afain	brl	braille
agst	against	chn	children
alm	almost	concv	conceive
alr	already	concvg	conceiving
al	also	cd	could
alth	although	dev	deceive
alt	altogether	devg	deceiving
alw	always	dcl	declare
bec	because	dclg	declaring
bef	before	ei	either

fst	first
fr	friend
gd	good
grt	great
herf	herself
hm	him
hmf	himself
imm	immediate
xs	its
xf	itself
lr	letter
ll	little
mch	much
mst	must
myf	myself
nec	necessary
nei	neither
o'c	o'clock
onef	oneself
ourvs	ourselves
pd	paid
percv	perceive
percvg	perceiving
perh	perhaps
qk	quick
rcv	receive
rcvg	receiving
rjc	rejoice
rjcg	rejoicing
sd	said
shd	should
sch	such
themvs	themselves
thyf	thyself
td	today
tgr	together
tm	tomorrow
tn	tonight
wd	would
yr	your
yrf	yourself
yrvs	yourselves

Appendix B

Early Braille Contractions

The following is a summary of braille contractions as they were presented in the Dictionary of Braille Contractions published in 1902 by the British and Foreign Blind Association in London. Words in parentheses indicate current contractions which have replaced the older ones; additional contractions are not indicated.

Alphabetic Whole Word Contractions

but	Jesus (just)	some (so)
Christ (can)	Lord (like)	that
every	not	unto (us)
from	people	very
God (go)	quite	you
have	right (rather)	will

Contractions Using Special Characters

and	for	of	the	with	gh	sh
ch	er	ou	th	wh	st	ing
ed	ble/	ow				

Whole Word Contractions Formed From The Above

child shall this which

Contractions Using Lower Signs

be* con* dis* en to# his#

in was# by* com*

*Only when used as the first syllable or a prefix.

#Only when used as a whole word.

/Only when appearing at the end of a word.

Initial Letter Contractions

Dot 5	ever	father	mother	under
Dots 4 and 5	word	those	whose	
Dots 4,5 and 6	world			

Final Letter Contractions

Dots 5 and 6	ence	self*	ong	ful
	tion	ness	ment	
Dots 4 and 6	ance	sion	less	
Dot 6	ation			

Besides the addition, change and deletion of contractions, some changes have been made in the characters assigned to punctuation as follows:


formerly ? now has no punctuation meaning


formerly ‘ (open single quote) now ? and “ (opening double quote)


formerly ’ (closing single quote) now ” (closing double quote)


formerly indicated the end of a line of poetry, but is no longer used


formerly indicated italics, now used to indicate a capital letter

Some other marks of punctuation such as brackets, double quotation marks, astericks, bar or fraction lines, ellipsis, accent sign and capital sign, had no braille sign indicated. It should be noted that the capital sign is used only in

elementary texts and not in general literature in those countries following the British conventions.

Appendix C

Grade One And One Half Contractions

Grade I and 1/2 braille uses forty-four contractions, all of which are contained in Grade II braille, and stricter rules prohibiting contractions from overlapping syllables are employed.

Whole Word Contractions

as	just	shall
but	knowledge	so
can	like	that
do	more	this
every	not	us
from	out	very
go	people	which
have	quite	will
it	rather	you

Whole and Part Word Contractions

and	in	the
for	of	with

Part Word Contractions

ar	gh	ow
ed	ing	sh
en	ou	th
er		wh

Appendix D

BRAILLE READING TEST

Name _____

Paragraph "SPACE"	standard	revised
	best	sphere
	uneasy	pineapple
	severe	painstaking
	beets	bellowing
	erection	really

Time _____

Recording errors

Place a "c" above a word if the reader automatically corrects himself.

Draw a wavy line under a word if the reader hesitates on it.

Write out phonetic spelling of a word if it is misread.

Encircle a word, syllable or letter omitted.

Use a caret to write in additional words read.

Draw a line under a word for each time it is repeated.

SPACE

"Space is the future of man" is the PREDICTION of D. Brainerd Holmes. Mr. Holmes' concern is not with the SPHERE on which we live, but the moon. He is confronted with the UNEASY task of heading the U.S. effort to reach the moon. This UNFULFILLED ambition of mankind BECKONS as one of the most challenging projects imaginable. At BEST, the prospect is not very reassuring, for a manned voyage to

the moon is far more difficult than most people think. However, Mr. Holmes has PARTAKEN in EQUALLY difficult projects. He supervised both the ERECTION of B.M.E.W.S., our northern radar defense, and the Talos missile program. It seems unlikely that there could be a BETTER or more enthusiastic engineer to supervise our space planning.

Time _____

Paragraph "ELEPHANT"	standard	revised
changeable	better	
beckons	uneasy	
equally	feverishly	
prediction	partaken	
unfulfilled	beefy	

Time _____

ELEPHANT

Portland, Oregon first heard the news last January tenth. A ten year old Siamese elephant, Belle, at the local zoo was eighteen months pregnant and one thousand pounds overweight, which is a bit BEEFY even for an elephant. Previous to this discovery the zoo men had been UNEASY about Belle's recent CHANGEABLE moods. PAINSTAKING preparations were undertaken so that Belle would not trample her young offspring. Expectant elephants must eat something constantly, whether it be oats, PINEAPPLE, or BEETS! Belle was no exception and

the keepers worked FEVERISHLY to keep her satisfied. Finally, after more than three months the precautions REALLY paid off. In the early morning hours of April thirteenth, Belle began thrashing and BELLOWING. Five hours later the SEVERE labor was over and Belle was the mother of a 225 pound baby elephant!

Time _____

Comments:

```
COM   BRAILLE SEARCH PROGRAM                                                  *
* $ = -BRAILLE-SEARCH +*.+ -START-AT- +A+*. // *RAL4, *WAM1 2 3 4 5   *
* $ = // *RCK1  *
READ $ = 1 + A  // *RCK2, .G500 READ
DELETE  $ + *. = 1 // *Q1 1 DELETE
* $ = *Q/.0 + A + 1 // *A1 2  *
AND *Q+$+$3+$22+A+N+D+$+- = 2+3+4+5+6+7+8+*.+1/.11+4+5+6+7+8+9 -
// *Q1 1 2, *WAM3 4 5 6 7 8 9 AND
* *Q = 1 + 1/.0 + A // *WSM1, *A1 3 *
FOR *Q+$+$3+$22+F+O+R+$+- = 2+3+4+5+6+7+8+*.+1/.11+4+5+6+7+8+9 -
// *Q1 1 2, *WAM3 4 5 6 7 8 9          FOR
* *Q = 1 + 1/.0 + A // *WSM1, *A1 3 *
OF *Q+$+$2+$23+O+F+$+- = 2+3+4+5+6+7+*.+1/.11+4+5+6+7+8 -
// *Q1 1 2, *WAM3 4 5 6 7 8          OF
* *Q = 1 + 1/.0 + A // *WSM1, *A1 3 *
THE *Q+$+$3+$22+T+H+E+$+- = 2+3+4+5+6+7+8+*.+1/.11+4+5+6+7+8+9 -
// *Q1 1 2, *WAM3 4 5 6 7 8 9       THE
* *Q = 1 + 1/.0 + A // *WSM1, *A1 3 *
WITH *Q+$+$4+$21+W+I+T+H+$+- = 2+3+4+5+6+7+8+9+*.+1/.11+4+5+6+7+8+9+ -
10 //*Q1 1 2, *WAM3 4 5 6 7 8 9 10 WITH
* *Q = 1 + 1/.0 + A // *WSM1, *A1 3 *
IN *Q+$+$2+$23+I+N+$+- = 2+3+4+5+6+7+*.+1/.11+4+5+6+7+8 -
// *Q1 1 2, *WAM3 4 5 6 7 8          IN
* *Q = 1 + 1/.0 + A // *WSM1, *A1 3 *
AR *Q+$+$2+$23+A+R+$+- = 2+3+4+5+6+7+*.+1/.11+4+5+6+7+8 -
// *Q1 1 2, *WAM3 4 5 6 7 8          AR
* *Q = 1 + 1/.0 + A // *WSM1, *A1 3 *
CH *Q+$+$2+$23+C+H+$+- = 2+3+4+5+6+7+*.+1/.11+4+5+6+7+8 -
// *Q1 1 2, *WAM3 4 5 6 7 8          CH
* *Q = 1 + 1/.0 + A // *WSM1, *A1 3 *
ED *Q+$+$2+$23+E+D+$+- = 2+3+4+5+6+7+*.+1/.11+4+5+6+7+8 -
// *Q1 1 2, *WAM3 4 5 6 7 8          ED
* *Q = 1 + 1/.0 + A // *WSM1, *A1 3 *
EN *Q+$+$2+$23+E+N+$+- = 2+3+4+5+6+7+*.+1/.11+4+5+6+7+8 -
// *Q1 1 2, *WAM3 4 5 6 7 8          EN
* *Q = 1 + 1/.0 + A // *WSM1, *A1 3 *
ER *Q+$+$2+$23+E+R+$+- = 2+3+4+5+6+7+*.+1/.11+4+5+6+7+8 -
// *Q1 1 2, *WAM3 4 5 6 7 8          ER
* *Q = 1 + 1/.0 + A // *WSM1, *A1 3 *
GH *Q+$+$2+$23+G+H+$+- = 2+3+4+5+6+7+*.+1/.11+4+5+6+7+8 -
// *Q1 1 2, *WAM3 4 5 6 7 8          GH
* *Q = 1 + 1/.0 + A // *WSM1, *A1 3 *
OU *Q+$+$2+$23+O+U+$+- = 2+3+4+5+6+7+*.+1/.11+4+5+6+7+8 -
// *Q1 1 2, *WAM3 4 5 6 7 8          OU
* *Q = 1 + 1/.0 + A // *WSM1, *A1 3 *
OW *Q+$+$2+$23+O+W+$+- = 2+3+4+5+6+7+*.+1/.11+4+5+6+7+8 -
// *Q1 1 2, *WAM3 4 5 6 7 8          OW
* *Q = 1 + 1/.0 + A // *WSM1, *A1 3 *
SH *Q+$+$2+$23+S+H+$+- = 2+3+4+5+6+7+*.+1/.11+4+5+6+7+8 -
// *Q1 1 2, *WAM3 4 5 6 7 8          SH
* *Q = 1 + 1/.0 + A // *WSM1, *A1 3 *
ST *Q+$+$2+$23+S+T+$+- = 2+3+4+5+6+7+*.+1/.11+4+5+6+7+8 -
// *Q1 1 2, *WAM3 4 5 6 7 8          ST
* *Q = 1 + 1/.0 + A // *WSM1, *A1 3 *
TH *Q+$+$2+$23+T+H+$+- = 2+3+4+5+6+7+*.+1/.11+4+5+6+7+8 -
// *Q1 1 2, *WAM3 4 5 6 7 8          TH
* *Q = 1 + 1/.0 + A // *WSM1, *A1 3 *
WH *Q+$+$2+$23+W+H+$+- = 2+3+4+5+6+7+*.+1/.11+4+5+6+7+8 -
// *Q1 1 2, *WAM3 4 5 6 7 8          WH
* *Q = 1 + 1/.0 + A // *WSM1, *A1 3 *
ALLY *Q+$+$4+$21+A+L+L+Y+$+- = 2+3+4+5+6+7+8+9+*.+1/.11+4+5+6+7+8+9+ -
10 //*Q1 1 2, *WAM3 4 5 6 7 8 9 10          ALLY
* *Q = 1 + 1/.0 + A // *WSM1, *A1 3 *
ANCE *Q+$+$4+$21+A+N+C+E+$+- = 2+3+4+5+6+7+8+9+*.+1/.11+4+5+6+7+8+9+ -
10 //*Q1 1 2, *WAM3 4 5 6 7 8 9 10          ANCE
* *Q = 1 + 1/.0 + A // *WSM1, *A1 3 *
ATION *Q+$+$5+$20+A+T+I+O+N+$+- = 2+3+4+5+6+7+8+9+10+*.+1/.11+4+5+6
+7+8+9+10+11 //*Q1 1 2, *WAM3 4 5 6 7 8 9 10 11  ATION
* *Q = 1 +1/.0 + A // *WSM1, *A1 3  *
ENCE *Q+$+$4+$21+E+N+C+E+$+- = 2+3+4+5+6+7+8+9+*.+1/.11+4+5+6+7+8+9+ -
10 //*Q1 1 2, *WAM3 4 5 6 7 8 9 10          ENCE
* *Q = 1 +1/.0 + A // *WSM1, *A1 3  *
FUL *Q+$+$3+$22+F+U+L+$+- = 2+3+4+5+6+7+8+*.+1/.11+4+5+6+7+8+9 -
// *Q1 1 2, *WAM3 4 5 6 7 8 9          FUL
* *Q = 1 +1/.0 + A // *WSM1, *A1 3  *
ITY *Q+$+$3+$22+I+T+Y+$+- = 2+3+4+5+6+7+8+*.+1/.11+4+5+6+7+8+9 -
// *Q1 1 2, *WAM3 4 5 6 7 8 9          ITY
* *Q = 1 +1/.0 + A // *WSM1, *A1 3  *
ONG *Q+$+$3+$22+O+N+G+$+- = 2+3+4+5+6+7+8+*.+1/.11+4+5+6+7+8+9 -
// *Q1 1 2, *WAM3 4 5 6 7 8 9          ONG
* *Q = 1 +1/.0 + A // *WSM1, *A1 3  *
BLE *Q+$+$3+$22+B+L+E+$+- = 2+3+4+5+6+7+8+*.+1/.11+4+5+6+7+8+9 -
// *Q1 1 2, *WAM3 4 5 6 7 8 9          BLE
* *Q = 1 +1/.0 + A // *WSM1, *A1 3  *
ING *Q+$+$3+$22+I+N+G+$+- = 2+3+4+5+6+7+8+*.+1/.11+4+5+6+7+8+9 -
// *Q1 1 2, *WAM3 4 5 6 7 8 9          ING
* *Q = 1 +1/.0 + A // *WSM1, *A1 3  *
BB *Q+$+$2+$23+B+B+$+- = 2+3+4+5+6+7+*.+1/.11+4+5+6+7+8 -
// *Q1 1 2, *WAM3 4 5 6 7 8          BB
* *Q = 1 + 1/.0 + A // *WSM1, *A1 3  *
CC *Q+$+$2+$23+C+C+$+- = 2+3+4+5+6+7+*.+1/.11+4+5+6+7+8 -
// *Q1 1 2, *WAM3 4 5 6 7 8          CC
* *Q = 1 + 1/.0 + A // *WSM1, *A1 3  *
DD *Q+$+$2+$23+D+D+$+- = 2+3+4+5+6+7+*.+1/.11+4+5+6+7+8 -
// *Q1 1 2, *WAM3 4 5 6 7 8          DD
* *Q = 1 + 1/.0 + A // *WSM1, *A1 3  *
EE *Q+$+$2+$23+E+E+$+- = 2+3+4+5+6+7+*.+1/.11+4+5+6+7+8 -
// *Q1 1 2, *WAM3 4 5 6 7 8          EE
* *Q = 1 + 1/.0 + A // *WSM1, *A1 3  *
FF *Q+$+$2+$23+F+F+$+- = 2+3+4+5+6+7+*.+1/.11+4+5+6+7+8 -
// *Q1 1 2, *WAM3 4 5 6 7 8          FF
* *Q = 1 + 1/.0 + A // *WSM1, *A1 3  *
GG *Q+$+$2+$23+G+G+$+- = 2+3+4+5+6+7+*.+1/.11+4+5+6+7+8 -
// *Q1 1 2, *WAM3 4 5 6 7 8          GG
* *Q = 1 + 1/.0 + A // *WSM1, *A1 3  *
JE *Q+$+-+B+E+$+- = 2+3+4+5+6+1/.11+3+4+5+6+*.+7 // *Q1 1 2 3 4 5, -
*WAM7 8 9 10 11  BE
* *Q = 1 + 1/.0 + A // *WSM1, *A1 3 *
COM *Q+$+-+C+O+M+$+- = 2+3+4+5+6+7+1/.11+3+4+5+6+7+*.+8  -
// *Q1 1 2 3 4 5 6, *WAM8 9 10 11 12 13          COM
* *Q = 1 + 1/.0 +A // *WSM1, *A1 3 *
CON *Q+$+-+C+O+N+$+- = 2+3+4+5+6+7+1/.11+3+4+5+6+7+*.+8  -
// *Q1 1 2 3 4 5 6, *WAM8 9 10 11 12 13          CON
* *Q = 1 + 1/.0 +A // *WSM1, *A1 3 *
DIS *Q+$+-+D+I+S+$+- = 2+3+4+5+6+7+1/.11+3+4+5+6+7+*.+8  -
// *Q1 1 2 3 4 5 6, *WAM8 9 10 11 12 13          DIS
* *Q = 1 + 1/.0 +A // *WSM1, *A1 3 *
// *WAM1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142
TOTAL  142*
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