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Abstract

The numbering and identification of parts within a manufacturing organization is of immense importance, for it serves as a major means of communicating information throughout the organization. The oldest, and still most prominent method of part identification is the use of meaningful, alpha/numeric part numbers. With the transition to computer assisted manufacturing systems, however, many of the weaknesses of this type of system have come to light. A newer approach to part numbering, the use of all numeric, non-significant part numbers as a vehicle for identifying parts and accessing the required information about each, may be a major contributor to improved communications in the computer age. This paper explores both approaches to part identification, addressing the advantages and drawbacks of each. It is concluded that the use of non-significant numbering, is indeed, the best approach to a flexible, simple, and standardized identification system, allowing access to all pertinent part information without incorporating that information into the part number. Two case studies, one of a leading compressor manufacturer, and the other a producer of greeting cards, are presented, demonstrating the feasibility of a conversion from significant to non-significant systems and the benefits obtainable. The problem of reducing data entry errors and maintaining data integrity with non-significant part numbers is analyzed and a proposed algorithm presented. Finally routines are demonstrated for both generating and then vetting and validating non-significant numbers.

1. Introduction

The true importance of part numbering systems in manufacturing organizations is often overlooked by executives. Complex or cumbersome numbering schemes not only impair communication within a company, but also inhibit the achievement of fundamental management objectives. Accordingly, it is unfortunate that the design and implementation of such schemes is usually left to the engineering department, rather than being the result of a company wide effort.

The goals of a part identification system can be listed as follows:

- Unique and unambiguous identification of each item
- Elimination of transmittal errors
- Minimization of the risk of creating new part records accidentally
- Prevention of inventory duplication
- Elimination of obsolescent and slow moving inventory (OSMI)
- No need for expertise to "recognize" part numbers

In attempting to achieve these goals, the traditional approach to part identification systems has been to create significant part numbers, which are intended to evoke recognition of certain characteristics of an item or part, e.g., its size, shape, material, color, function, etc., by the part number itself. Considerable time and effort have been expended by engineering experts in the development of part coding and classification schemes, which often result in bulky volumes filled with instructions, illustrations and examples to assist users in the application of these techniques.

Part coding and classification is the key to advanced applications such as automated process planning, group technology manufacturing and inventory classification. Unfortunately, traditional thinking has trapped most companies into condensing all of the necessary attributes into one single item identification record: the Part Number.

The tradition of significant part numbering is largely due to manual techniques in which any knowledge of a part's characteristics from its part number was perceived as beneficial. The advent of computer systems, which can provide easy access to a myriad of information items through a single, even arbitrary, part identifier, make significant numbering unnecessary. In fact, significant numbering can interfere with the implementation of new computer aided manufacturing systems, which require a disciplined, simple, and common language by which items are engineered, purchased, processed, and sold. Further, computer systems provide the capability of part number vetting and validation to ensure data integrity and security; such protection schemes may become very complicated, and therefore costly, if sophisticated and meaningful record structures are to be maintained.

The alternative approach is to use simpler, non-significant part numbering schemes, in which the part numbers serve only as a means of identification for parts, not meant to describe, in any way, the physical characteristics or functions of these parts. With this number, however, it is possible to obtain these and any other pieces of information describing the parts through an on-line computer system.

As noted by Elliot (1985), the crucial concern over part numbering should not be the simple question of significant versus non-significant, but, more importantly, how to best control and maintain the part information necessary within an organization. In this age when computerized management tools are used in almost every manufacturing organization, non-significant numbering clearly is the better choice from this perspective.

This paper discusses both approaches to part numbering systems, addressing the potential benefits and tradeoffs of each. To support the case for non-significant numbering schemes, case studies of two leading manufacturers are reviewed. The problems of data security and integrity are specifically addressed, and a mathematical algorithm is developed aimed at minimizing data entry and transmission errors. The creation of non-significant part numbers utilizing check digits is effected automatically by a computerized number generator. Finally, a checking routine for vetting and validating these numbers as they are entered on-line is automatically invoked and used to safeguard data integrity.

2. Significant Alpha/numeric Part Numbers

2.1 The Basic Philosophy

Before the computer era, functions such as product design, production planning, product manufacturing, and inventory control were performed manually. As a result, it was essential, in the interest of efficiency, for users to be able to recognize parts without always refrencing pertinent documents such as drawings and parts lists. To satisfy this need, several part classification schemes have been developed and implemented, traditionally by design engineers, to create significant part numbering systems.

Designing and formatting significant part numbers within an organization is no trivial task, and due to the often isolated groups involved in such projects, generally results in the lack of a standard scheme, even within a single company. A typical part numbering system may call for the incorporation of the following attributes into one single field:

1. Part number proper - usually numeric and short in length
2. End product number and product type
3. Drawing type (isometric, orthographic, etc) and size
4. Part type (bearing, plate, etc.) and key part dimensions
5. Material code
6. Source code (make or buy)
7. Cost and inventory code
8. Unit of measure (accountability)
9. Where used
10. Supplier's identification

This list in not exhaustive, but does include most of the elements used in a meaningful part number. The philosophy of significant part numbering is shown in the following example presented by Carlson (1971).

Consider a thrust bearing used on the end of the crank shaft of a small diesel engine; the following are the codes used to identify it:

Using Product	Drawing Code	Product Code	Location	Source Code	UOM	Next Assy
1115-23	BDIV	13	3	35	EA	17681

Name	Size Code
Bearing	00.750D

These descriptive fields are merged to produce a single data field:

111523BDIV13335EA1768100750D

Using "only" 28 characters, a "part number" is created that is truly meaningful, if only one knows its coding and structure. As a further aid to users, the various fields may be separated by various symbols, producing a "structured" single field of 37 characters:

1115-23;BDIV,13,3:35/EA,17681,00.750D

If even one of these character fields becomes inadequate in meeting the needs of the organization, it is easy to imagine the chaos that would result from changing the field length, reprinting all relevant documents, catalogs, and so on. And yet, the part is still not uniquely identified, which defeats the most fundamental principle of part numbering. Another bearing could have the same descriptive or coded fields and yet be different, since the system does not encode information on inside diameters, widths, quality certification requirements, design revision levels, or other features which make a part unique.

The primary advantage of this system is that it allows users to quickly recognize a part and its uses just be examining its part number, and to physically locate that part in the stores or on the shop floor. But considering the growing number and variety of parts residing on a typical manufacturing data base, as well as the personal preferences of each engineering director or vice president who feels that the system should include his or her own personal touches, it is likely that such a system has probably known many variations during its lifetime. It is therefore difficult to find even one individual in a given organization who is fully confident with the system. Instead of this situation, we should strive to make all users familiar with the "company language" even those new to the organization.

The advantage of part recognition is outweighed by a number of disadvantages encountered in the application of the system described above:

a. Part numbers tend to become too long. Statistical results presented by Sedgwick have shown that a 10% error rate is experienced if part numbers are up to 10 digits long. Numbers with 10-20 digits induce some 50% erroneous transcriptions, and numbers over 20 digits are beyond practical applications.

b. Part numbers may not be unique. For a significant, unique, and comprehensive codification of a part, a large number of parameters must be considered and formatted, so large that the limit of practical applications is exceeded (Harhalakis, 1984).

c. Running out of numbers and characters. Most subdivisions within structured part numbers rely upon using one single alphabetic or numeric character to describe, under coding, some of the part's features. Thus the need to increase the field size to two or more positions often arises, creating even more confusion and burden to keep documentation up to date.

d. Considerable need for user training. Newly employed engineers have to undergo an intense training exercise so that they become familiar with part number coding and structuring, according to the rules of their employing company. This knowledge, which is acquired with considerable capital investment, is of no use as soon as employees move to another company.

e. Unnecessary burden to maintain drawings, documents, and manuals. Every time a new rule is implemented to the part numbering scheme, a substantial number of existing drawings, parts lists, service and operation manuals must be updated. Customers are usually left with their original issues and a lot of confusion and disenchantment is usually experienced.

f. Computer-aided part retrieval, validation, and sorting is almost impossible. In many circumstances retrieval of parts based on a certain characteristic is of utmost importance, especially during the design and process planning stages. If the characteristic is question is depicted by a sub-field within the structured part number field, such a retrieval becomes cumbersome, since special programs have to be written, tested, and run against the engineering data base. Similar, if not more severe problems are encountered with record validation and sorting routines.

g. Confusion with vendors' numbers. The average manufacturing company in the U.S. purchases almost 50% of the items listed on their parts lists, either as raw materials or as finished parts. Sometimes ordering, but certainly receiving these parts is performed using the vendors' part numbers. It is very difficult, however, to distinguish between "own" and foreign numbers in the absence of a computerized vetting routine, hence the adoption and use of foreign numbers has become very common. The major drawback of such a practice is that the whole system of structured part numbers within the organizations is severely abused.

These drawbacks are particularly troublesome in today's transition to automated manufacturing systems, which are most effective when used with a simple, disciplined, and standard identification system. The use of significant part numbering systems complicates this transition, and may even lead to failure of the system; too often, the blame for such failures is placed on the software, rather than on the part numbering system which was not designed to accommodate computerization. It is therefore surprising to see statements of the type "a (part) identifying number (should) define the contents of the item unambiguously" in publications promoting MRP (Orlicky, 1975).

2.2 Engineering Changes and Significant Numbering

To assist and formalize decision making in design changes, most manufacturing companies have implemented some form of "interchangeability rules". Newer techniques assume the use of Bills of Materials (BOM), structured in a family tree form, to relate the manufacturing sequence of operations required to produce the end product. If a modified part within the BOM structure requires a new part number (as determined by the rules of interchangeability), it is likely that the next level parent in the BOM will be affected, requiring the use of the interchangeability rules once again. Should this parent require a new part number, the next level parent must again be examined, and so on. If a part is reached requiring only a design revision number (or letter) change to satisfy the rules of interchangeability, then it is most likely that no further changes will be required in parts residing at higher levels. This procedure must be applied "sideways" as well as "upwards"; both neighboring components and components physically located near an altered component should be checked for potential changes. If changes are required, their parents must be checked as well (Harhalakis, 1985).

In the majority of design changes (70-80%), the final result is minor modifications to one or a small group of parts, which are assigned a new design revision number or letter. Typically, in the authors' experience, the revision letter or number becomes a part of the part number, usually appended to it as a suffix, which only adds to the length and confusion of the whole meaningful part numbering scheme. Further, the extra character at the end of the part number field, strictly speaking, changes the whole record, defeating the concept of a mere revision change altogether, and assigning to the part a new part number. For example, the part number XXXX may become XXXX-A, which is no longer the same part number.

2.3 Group Technology and Significant Part Numbering

The increasing demand for customized products in a highly competitive industrial environment has led manufacturers towards small, and therefore less economical, lot sizes. This trend, along with improved materials and quality standards, has forced changes in the conventional job shop layout and in the way design and manufacturing functions interact; no longer are these activities thought to be isolated from each other. One technique promising to meet these current and future challenges is Group Technology (GT). It was identified by Groover (1980) as a manufacturing philosophy in which similar parts are identified and grouped together to take advantage of their simularities in manufacturing and design. Group Technology categorizes alike parts into families with similar design and/or manufacturing features. Each member of a given family would therefore require similar design algorithms and manufacturing processes. As a result, it is possible to classify a large data base of tens of thousands of parts into perhaps 50 or 60 distinct families which can be processed through machine groups, or cells, each one capable of producing one or more families of parts.

In engineering new parts, existing designs of similar parts can be used as a starting point, on an "as is" or "modify as needed" basis. The use of a coding scheme, whereby the identification and relation of parts similarities are reflected by design attributes (i.e., geometric shape, size, etc.) facilitates this process.

One of the results of GT development and implementation in manufacturing organizations has been the creation of yet another two records associated with each manufactured part: the GT design and the GT manufacturing code. Several methods can be used to structure the contents of these codes: Hierarchical, Chain-type, and Hybrid to name only the most predominant classified by Ham (1976). Following the meaningful part numbering philosophy, most manufacturers have made the GT codes part of their part numbers. A common use of the GT concept in production flow analysis is illustrated in the following example presented by Groover (1980):

Pt/No	GT Code
1 5 7 8 4	0 1 0 4 1 0 1 9 2 3

The GT manufacturing in this example is used to indicate the processes and machines employed to make this part, structured into 5 two digit sub-fields as follows:

01 = cutoff
04 = chucker
10 = grind-exterior cylinder
19 = clean
23 = inspect

A look-up table is maintained in any given job shop detailing the codes for all the available machines,tools, and types of operations.

The use of GT codes as described here is a classic example of misusing part numbers to indicate how parts are made rather than simply for identification purposes. Fairly routine matters such as changing manufacturing routings or updating machines and processes confuses further the whole part numbering scheme, and may have many of the same effects described in Section 2.1.

3. Non-significant, All Numeric, Part Numbers

3.1 The Basic Philosophy

Carlson (1971) suggests that a part number should represent a part in the same manner as a Social Security Number represents a person. Each number is unique and identifies only one person, but does not describe any feature of that person (e.g., height, weight, address, race, etc.). It never changes for a given individual and the numbering system can accommodate many millions of people more than required.

Like a Social Security Number, a part number serves as a basic item of communication within and outside a company, and is crucial to the information system of that company. It is the key to accessing information about the part including its design and manufacturing features, size, location, status, and a host of other pertinent data elements, all stored in separate data fields.

The fundamental entries into a Part Master Data system are the part number and part description, such as:

Part No: 76310355

Part Description: Bearing 1/2 ID x 3/4 OD

There is no significance to the part number, and further, it has no relationship with the contents, form, shape, or any other features of the physical part. Part numbers are generated sequentially and are usually assigned from a general register book in the engineering department. Mathematical techniques for incorporating security and error detection routines for part number transactions are explored in section 5.

The approach outlined here does not suffer from the drawbacks discussed in Section 2.1. In fact, the implementation of a simple, non-significant numbering scheme, supported by a Manufacturing Resource Planning (MRP II) system may deliver all of the benefits claimed by significant part numbers and more.

Table 1 identifies the typical computerized transactions/screens available in an MRP II system to accommodate and process data recorded in the part number record in a conventional significant part numbering system.

As demonstrated in Table 1, the underlying philosophy of non-significant part numbering is that the part number should serve only as an access vehicle for data items maintained in different data records in various modules of the host system. Modifications to any of these data records should in no way affect the part identification number, unless the changes require consideration for an Engineering Change, in which case the rules of interchangeability should be applied, as outlined in Section 2.2.

Some of the benefits of non-significant part numbering schemes are as follows:

a. Part numbers are of a fixed length (e.g., 8 digits as in the above example).
b. Part numbers are unique
c. No risk of running out of numbers as long as an adequate range is initially selected.
d. No need for user training on part recognition, assuming that the system and access terminals are readily available
e. Elimination of the burden of continually updating drawings, documents, and manuals.
f. Ease of retrieval, validation, and sorting of part numbers.
g. No confusion with vendors' numbers
h. Reduction of transciption errors, assuming that a computerized validation routine is implemented.

i. **Prevention of inventory duplication and obsolescence.**

Though hard to quantify, the cost effectiveness of non-significant part numbers to the whole organization is apparent. Even the cost required to change from a significant part numbering system to a non-significant scheme can be quickly paid back with the savings incurred.

There is, however, a limitation to this method, in that retrieval of parts is difficult, if not impossible, if the required part numbers are not available to the user at the time of inquiry. This problem has understandably been a cause for concern over the past few years; the most promising solution appears to be the use of disciplined part descriptions. This concept is discussed in the following section.

3.2 Part Retrieval via Generic Description Schemes

In spite of the efforts of the federal government in general and the Department of Defense in particular (MIL-STD-28, 1958), as well as those of several private industries to introduce some disciplined standardization into drawings and part descriptions, typically parts are still described in a way most understandable to the individual draftsman or engineer, which may or may not make any sense to others. As a result, similar parts differing only in size are often described in totally different formats: CYLINDER PISTON 5" DIA X 7" LONG and 4" DIA X 5" LONG STAINLESS STEEL PISTON. In addition to the different formats, the second description includes a material specification, which is generally not necessary, since a separate data record is usually reserved for this purpose.

Two main reasons are driving large organizations toward adopting the idea of standardization in part descriptions:

a. Ease and effectiveness of data communication between departments and plant locations

b. Ability of developing and implementing a computer assisted search routine for part retrieval, based on part description.

The basic concept of generic description schemes is to use the key descriptive word at the beginning of the field, followed by other explanatory words and size information (Harhalakis, 1984). Using this approach, the description of the aforementioned part would be: PISTON CYLINDER 5" DIA X 7" LONG. Using this type of description system allows for a program to be developed to facilitate the retrieval of parts, together with their part numbers, by simply keying in the desired key words. For example, if "PISTON" were keyed in, the result would be a list of all parts whose descriptions begin with "PISTON", their part numbers, and their complete descriptions. Because such a list could be quite lengthy, the inclusion of further descriptive words in the request could be used to further narrow down the possibilities; "PISTON CYLINDER" for example, would eliminate such items as valve and pump pistons from consideration. Such a technique has been successfully developed and implemented at the premises of a leading compressor manufacturer in the United Kingdom (Harhalakis, 1984).

By using a combination of a non-significant part numbering scheme and a well disciplined part description format, the problem of part retrieval can be virtually eliminated. For convenience, a list of the most common key words can be issued on a company wide basis, to serve as a quick reference for the creation of new part descriptions. It can be kept in a computer file and used as a look up table. Such a list should be updated as required to accommodate new part families and other changes that require new key words.

3.3 Distinction Between Part and Drawing Numbers

traditionally, the drawing number and the part number have been thought of as one and the same entity. More recently, however, the use of computer-aided systems, which require precise data control and entry, has brought to light the problems caused by exceptions resulting from this approach. Further, an engineering drawing of a physical part no longer represents that part on a one-to-one basis; more than one item can be illustrated on the same drawing (e.g., screws of the same type and diameter differing in length only) or one can have a general lay-out drawing or instructions sheet that has a drawing number but no physical part content.

As another example, engineers typically do not produce a separate drawing for the casting of a finished machined item, which means that the casting itself does not have its own drawing number. This is generally true for the patterns used to mold and cast castings as well. Certain purchased items, such as switches, valves, gauges, etc., are often not drawn on "in-house" engineering drawings, again depriving these parts of drawing numbers. The opposite problem also occurs, as one single complex item may have more than one drawing (e.g., orthographic, isometric, solid modeled, exploded, etc.). The use of Computer Aided Design (CAD) systems, which support a variety of views, makes this problem more pronounced.

The obvious answer to these problems is to separate the two different numbers, storing each in a separate data record. This should be facilitated by the Engineering Transaction screen, which should allow for a separate entry of each number, and further, should allow for a multiple relationship between part and drawing numbers. Such a system allows for cross referencing during inquiries; an inquiry via the part number would produce a list including all drawing numbers related to the part, and inquiries via a drawing number would provide a list of all part numbers illustrated on that drawing. This technique finds numerous applications in facilitating engineering and receiving type of activities as described by Harhalakis (1984).

4. Case Studies: Ingersoll Rand & American Greetings

Ingersoll Rand is a compressor and pump manufacturer known worldwide with a sales volume exceeding $4 billion each year, with plants in more than seventeen countries. The company recognized the advantages of a non-significant, all numeric part numbering system in 1966 and decided to make a transition to such a system on a worldwide basis. The decision to make this move on a worldwide basis was expected to have a greater impact than if done at a single facility, since it would eventually alleviate the former problems in intercompany communication of engineering data, spare parts orders, and identification of receipts. Communications suffered due to the fact that a given part might have different significant part numbers at different locations, since different coding schemes were used at various plants. In addition to the confusion and communication problems caused by this situation, substantial levels of idle inventory were common.

The new part numbering system was called Corporate Communication Numbering (CCN) system and it used seven digits to identify parts, plus a single check digit at the end of the field, for a combined number of eight digits, e.g., 38274957. This system accommodates 10 million parts within the range 0 to 9,999,999; this range was chosen as a compromise between minimum length and adequate quantity of part numbers.

The Wythenshawe plant of Ingersoll Rand, in the United Kingdom, experimented with the CCN system for several years before deciding to make the formal transition in 1983. This delay was largely the result of two reasons: (a) lack of appropriate software to check and validate CCN's within an approved Bill of Materials module, and (b) lack of hardware communication links between Wythenshawe and the U.S. plants, and especially with the corporate headquarters in Woodcliff Lake in New Jersey.

The transition to the CCN system was not without its problems; frustration and apprehension of users, customer reactions, and organizational restructuring have all been part of the process. Nonetheless, the system has managed to overcome these problems, largely as a result of the corporate commitment to the change. Currently, some 95% of existing parts and all newly engineered parts are assigned CCN's common to all plants worldwide. Ingersoll Rand has established a CCN center in Easton, Pennsylvania, which is in constant contact with all the manufacturing plants, to coordinate the allocation of numbers. When an old drawing is retrieved for use in a product, it must be given a CCN. First, information about the part is transmitted to Easton, to determine if the part has already been used in a product, hence already assigned a CCN. If not, a new CCN is assigned, and a record created on the data base for future use by all plants. In the case of newly engineered parts, a CCN number is assigned, a standardized generic description given, and the information transmitted to Easton.

Primarily for psychological reasons, it was decided to temporarily maintain both the old part numbers and the new CCN's. Even so, the driving force of their MRP II system is the CCN, though during certain transactions, the old part number (if applicable) is also displayed. Cross referencing old numbers and CCN's is also possible by inquiring via the old part number.

Following the philosophy of non-significant part numbering, data fields separate from the CCN are maintained, containing various data pertaining to each part. A typical engineering data transaction screen from the Wythenshawe plant is shown in Figure 1, and shows some of the data fields available. The Wythenshawe plant uses the CIMS system from Cullinet Software, Inc. as their manufacturing system; the system has been modified to accept contractual manufacture of special compressors. As shown in Figure 1, most of the entries related to item master data and listed in Table 1 are provided here in fields separate from both the CCN and the old part number. Each time a CCN is entered, the number is vetted and validated via the check digit routine. If an error has been made, a warning message is returned "Invalid CCN". If a valid CCN is entered that has not yet been assigned to a part, the message is "CCN does not exist". Whenever a new part master record is created, both the CCN and part number are entered (in separate fields) and either one can then be used to access the part. In the event of a new part without an old part number, the CCN is entered into both fields. The system uses other screens for product structures (gozinto), inventory and purchasing types of data.

Despite the cost of creating and maintaining the coordinating center at Easton, Ingersoll Rand has enjoyed substantial cost savings from the implementation of the CCN system. The company has finally achieved commonality of data, with minimum transcription errors and self-assured data integrity. In addition, an added degree of flexibility has been developed, allowing the engineering of products where the expertise exists, and their manufacturing where the overall cost is lowest.

Another example of a successful implementation of a non-significant part numbering system is the American Greetings Corporation in Cleveland, Ohio presented by Jackson (1985), which operates nine plants in five states and has annual sales of almost $1 billion. The system at this company incorporates automatic assignment of part numbers as soon as a new part record is added to the data base from any of the plant locations. The use of a uniform description and classification system is also used for creating part descriptions. As was the case with Ingersoll Rand, attempts were made to facilitate and cross reference old and new part numbers for older product lines during the transition. Although this program was originally intended primarily to serve the conversion of previously unnumbered material records for their MRP system, the company has found the new numbering system useful for inventory control of items such as tools and dies, maintenance supplies, and business forms, as well as raw materials, sub-assemblies, and end products. After two years of use, American Greetings claim excellent acceptance of the numbering system by users and feel that the system will be the key to integrating the various information systems now used in the various corporate departments.

5. Check Digit Algorithms

The use of one or more check digits appended to a nonsignificant number greatly reduces the possibility of an incorrectly typed part number being accepted by the system. Given the high data accuracy required by computer aided manufacturing systems, the adoption of some form of self-validation of part numbers is essential. Check digits are calculated by arithmetically combining each of the digits in the part number and then reducing the combination to the required number of digits. Many such algorithms are available, with the most common involving the multiplication of each digit by a multiplier, adding the products, and reducing the sum with modulus arithmetic.

Once a routine is established, a series of part numbers can be automatically generated by a computer and either manually or automatically assigned to items according to company procedures. An on-line vetting and verification program is then used to instantly check part numbers as they are entered into the system.

5.1 Error Detection with Check Digits

It should be noted that regardless of the algorithm used, a single check digit provides for only 10 possible values (digits 0 through 9), hence 10% of all part numbers will share the same check digit. Therefore, the highest possible error rate, i.e., the possibility of a randomly typed number being accepted by the system, is 10%. By providing two check digits, the highest possible error rate can be reduced to 1%, since there are 100 possible check values. In either case, however, the practical error rate can be made considerably less with a carefully chosen algorithm that precludes the most common data entry errors,(i.e., mistyping a single digit and transposing digits), from passing the system validation procedure.

As mentioned above, most check digit algorithms involve the multiplication of each digit by a given individual multiplier; the products of these multiplications are summed, and the check digit(s) are determined using modulus arithmetic. This procedure is shown below for a part number consisting of n digits and modulus 10 arithmetic:

digits	$A_1, A_2, A_3, \ldots, A_n$
multipliers	$m_1, m_2, m_3, \ldots, m_n$
sum	$S = \sum_{i=1}^{n} m_i A_i$

A single check digit, X, can be defined as

$$X = S \text{ MOD } 10$$

Alternatively, two check digits, XY, can be defined as

$$XY = S \text{ MOD } 100$$

The check digit(s) is then appended to the part number as an integral part of it.

The optimal selection of multipliers is the key to creating a system that will detect the following data entry errors, and therefore prevent the adverse effects of entering erroneous data into the system.

- Mistyping a single digit. Whether in print or handwritten, there are certain numbers that are commonly misidentified because of their similarily to another number, e.g., between 1 and 7, and between 3, 5, and 8. The system should be able to detect the mistyping of any single digit in the part number field.

- Transposition of digits. It is quite common to accidentally interchange a pair of digits, particularly in the middle of a long numeric field. The system should be able to prevent such a switch of adjacent numbers and numbers separated by one digit. Once separated by two or more digits, the chance of transposition is less likely, and hence not a major concern.

5.2 Appraisal of the Potential of the Modulus 10^k Algorithm

The following analysis explores the constraints in the choice and arrangement of multipliers for the algorithm described in order to meet the error detection requirements listed above.

Consider the general algorithm for a part number with n digits

$$A_1, A_2, \ldots, A_i, \ldots, A_n \quad (0 \leq A_i \leq 9)$$

and integer multiplers

$$m_1, m_2, \ldots, m_i, \ldots m_n \quad (m_i \geq 1)$$

To obtain the check digit(s) one starts from

$$S = \sum_{i=1}^{n} m_i A_i = \sum_{i=1}^{n} p_i \qquad (1)$$

where $p_i = m_i A_i$
S is the sum of individual products

which results in

$$X = S \text{ MOD } (10^k) \qquad (2)$$

where X is the check digit value
k is the number of check digits $(k \geq 1)$

The modulus operator provides the remainder of the division $S/(10^k)$, which, in effect, means subtracting the largest multiple of 10^k less than or equal to S from the sum S. A fundamental property of this function is that all numbers $S'=S\pm b(10^k)$, (b=any integer, $S'>0$), will result in the same remainder, hence the same check digit value. The key to reducing the acceptance of data entry errors by the system is to ensure that the common errors identified above cannot produce a sum differing from the correct sum by a multiple of (10^k).

Each of the two types of errors mentioned above will be considered separately.

5.2.1 Incorrectly typed single digits

Considering an incidental digit, A_i, within the part number field, the product

$$p_i = m_i A_i \qquad (3)$$

should be used for the calculation of the check digit(s). If A_i were typed incorrectly as A_i', rather than P_i, P_i' would be obtained:

$$p_i' = m_i A_i' \qquad (4)$$

If the total sum of products for the correct entry is S, and for the erroneous entry, S', then the sums of products differ by

$$S' - S = \Delta S = m_i A_i' - m_i A_i = m_i(A_i' - A_i) \qquad (5)$$

For the error to pass the system checks, ΔS should be such that

$$\Delta S = b(10^k) \qquad (6)$$

or

$$m_i(A_i' - A_i) = b(10^k) \qquad (7)$$

or, finally

$$m_i d = b(10^k) \qquad (8)$$

where $d = A_i' - A_i$ = difference between correct and incorrect digits. (for a given A_i, $-A_i \le d \le 9$, and $d \neq 0$)

Hence,

$$m_i = \frac{b}{d}(10^k) \qquad (9)$$

Since A_i can range from 0 to 9 ($0 \le A_i < 9$), it follows that d can range from -9 to 9 ($-9 \le d \le 9$, $d \neq 0$). Thus, for a single check digit, k = 1, and for any multiplier, m_i, which satisfies the following equation,

$$m_i = \frac{b}{d}(10) \qquad (10)$$

the error will pass the validation routine. Keeping in mind that m_i must be a positive integer, the solution of this equation over the ranges of b and d yields all multiples of 2 and 5, or,

$$m_i = \{2b, 5b\} \text{ for all integers b}$$

To avoid such an erroneous entry being accepted by the system, no multipliers m_i divisible by 2 and/or 5 should be used. This leaves all odd numbers not divisible by 5 as potential multipliers. Due to the modulus 10 operator, however, there are only four unique multipliers left after considering the above constraints: 1, 3, 7, and 9. All subsequent odd numbers, greater than 10 and not divisible by 5, (11, 13, 17, 19, . . . ,) produce the same remainders as one of the first four numbers.

For a two check digit number, k = 2, and all multipliers satisfying the relationship

$$m_i = \frac{\underline{b}(100)}{d}$$

should be avoided. Similarly, the solution to this equation produces all multiples of 20 and 25 i.e.,

$$m_i = \{20b, 25b\} \text{ for all integers } b$$

With two check digits the constraints are much less restrictive; any multiplier less than 20 can be used without the system ever accepting a number entered with a single digit error.

5.2.2. Transposition of digits

Let us assume that two incidental digits A_i and A_{i+j}, (where $1 \leq j \leq n-i$), with multipliers m_i and m_{i+j} respectively, have been interchanged during typing. The correct sum of products is S while the incorrect sum of products is S'. The difference between the two sums will be

$$S' - S = \Delta S = (m_{i+j}A_i + m_iA_{i+j}) - (m_iA_i + m_{i+j}A_{i+j}) \quad (11)$$

or

$$\Delta S = (m_{i+j} - m_i)A_i - (m_{i+j} - m_i)A_{i+j} \quad (12)$$

or, finally

$$\Delta S = (m_{i+j} - m_i)(A_i - A_{i+j}) \quad (13)$$

For the error to pass the system validation, ΔS should be a multiple of 10^k:

$$\Delta S = b(10^k) \quad (14)$$

or

$$(m_{i+j} - m_i)(A_i - A_{i+j}) = b(10^k) \quad (15)$$

or

$$d_m d_t = b(10^k) \qquad (16)$$

where $d_m = (m_{i+j} - m_i)$
$d_t = A_i - A_{i+j} \qquad (0 \le |d_t| \le 9)$

Which can be written as

$$d_m = \frac{b(10^k)}{d_t} \qquad (17)$$

Note that this form is similar to that in equation (9). Since d_t has the same range as d in equation (9), the solution is similar. For a single check digit, k = 1, eq. (17) yields all multiples of 2 and 5 as values of d_m to be avoided:

$$d_m = \{2b, 5b\} \text{ for any integer } b$$

Also, for two check digits, k = 2, and the solution is all multiples of 20 and 25:

$$d_m = \{20b, 25b\} \text{ for any integer } b$$

Hence, the constraints for avoiding transposition of digits are defined. These limitations indicate that the multipliers of pairs of part number digits which may be prone to transposition, including adjacent and alternate digits should not differ by the indicated amounts d_m, because there is at least one d_t, (i.e., difference between two part number digits), which would allow their interchange to pass the system checks.

The following example will illustrate the results of this analysis. For a number with a single check digit, if two correct adjacent digits and their respective multipliers are as follows:

digits	...7	2...	(differ by 5)
multipliers	...1	3...	(differ by 2)
products	...7	6 ...	
sum of products	=	13	

the transposition of these digits would produce:

interchanged digits	...2	7...	(differ by 5)
multipliers	...1	3...	(differ by 2)
products	... 2	21...	
sum of products	=	23	

But both 13 and 23 produce the same remainder, 3, when multiples of 10 are subtracted; hence an incorrect accpetance will occur. With these two multipliers, in this example, any digits differing by five, e.g., 1 and 6, 3 and 8, 4 and 9, would have the same problem. Note that if the digits had been 2 and 6, which differ by four, the transposition would have not been accepted.

To achieve protection from both types of errors described here, (erroneous entry of one digit and transposition of two digits), one must statisfy the constraints imposed by each; with a single check digit and modulus 10 arithmetic, however, the satisfaction of both constraints is impossible. Given the limited number of multipliers acceptable for the elimination of single digit errors, 1, 3, 7, and 9, which are all odd, the difference between any two of these must be an even number. This, however, violates the constraints necessary to elimate transposition errors, even for adjacent digits. To eliminate the possibility of transposition would require the use of even multipliers, which would in turn allow for some of the most common single digit errors, such as entering a 3 for an 8, or a 1 for a 7.

For this reason, the use of two check digits and modulus 100 arithmetic is recommended. As shown by the above analysis, any multiplier in the range $1 \leq m_i \leq 19$ will ensure that no single digit error could pass the validation scheme. Furthermore, any ordering of these multipliers, (as long as none are repeated), will prohibit any transposition errors, across any portion of the number, from being accepted. And finally, two check digits, as mentioned before, provide a highest (random entry) error rate of only 1%, which would help in the protection against errors more complicated that those examined here.

An algorithm previously proposed by Harhalakis and Khan (1985) suggested the use of only one check digit and modulus 10 arithmetic. For the sake of simplicity, however, the effect of the modulus 10 function when mistyping single digits and when interchanging alternating digits were not considered. As a result, some of the most common single digit errors (e.g., entering 3 for 8 or 1 for 7 and vice versa) would be accepeted in certain digit locations; the transposition of certain numbers would likewise be accepted.

Another algorithm proposed by Carlson (1983) uses modulus 11 arithmetic, which satisfactorily eliminates the two types of problems cited here while using only a single check digit. Using modulus 11, however, eliminates one-eleventh (9.1%) of the otherwise usable numbers within a given range, since one of the possible remainders, 10, cannot be accommodated in a single digit. As a result, it is quite possible that an extra digit location may be necessary to obtain the desired quanity of part numbers. However, the modulus 11 method still has a highest possible error rate of 10%. Therefore if an extra digit is to be used, it would be better utilized as a second check digit, which would lower the worst case error rate by a factor of 10. Such accuracy is well worth the extra storage and data entry time required, when one consideres the data accuracy required by MRP II and other manufacturing systems.

In addition to error protection, the part number algorithm and accompanying computer programs for generating and then validating part numbers on-line should be designed as efficiently as possible. This is especially critical for the vetting and validation program, since hundreds, if not thousands, of part numbers everyday may call for this program for data verification.

Two simple programs have been developed following these guidelines for a seven digit number with two check digits. With the flexibility of the two check digit system, the multipliers were chosen to be the simple series {1, 2, 3, 4, 5, 6, 7}. The two check digits are calculated as outlined above and then appended to the part number to produce a nine digit integrated part number.

A prime advantage of each of both programs is that they can accommodate part numbers of any length. Figure 2 shows a sample run of the part number generation program for part numbers 4000001 to 4000010. The program is capable of generating check digits for part numbers of any length, providing for as many parts as required.

The second program, written to validate numbers as they are entered on-line, uses the same routine of the part number generation program and would serve to halt any transactions involving incorrect part numbers as soon as the numbers are entered. The operater can then reenter the data with minimal time wasted. An interactive session with this program is demonstrated in Figure 3, which shows the rejection of some of the common typing errors descussed in this section.

6. Conclusions

The presence of computer assisted manufacturing systems, necessitates the reevaluation of the traditional methods for part identification. No longer are meaningful, significant part numbers the best way of communicating information inside and outside an organization; there are too many limitations to this approach. Instead, the power of computers to maintain, store, and retrieve data allows the assignment of unique part numbers to every part, which serve only as identifiers, while access to any desired information about that part is readily available. The assignment of numbers is simple and standardized, and the use of check digit algorithms can reduce the occurrence of data transcription errors to an acceptable level.

A simple part number generation algorithm has been presented, using two check digits to keep the highest possible error rate to 1%, and eliminating entirely the most common types of errors, mistyping a single digit within the numeric field, and transposing two digits withing the field. A second program is then used to vet and validate part numbers using the same algorithm as the part numbers are entered on-line.

The transition from significant to non-significant part numbering schemes is not without its problems, but this observation is true for virtually any new technology or methodology applied within an organization. It only takes good planning, user training, and implementation procedures to make the change successful. Further, such a transition is essential if the organization is to obtain any benefits from use of such systems as MRP II, CAD and CAM, and most importantly, Computer Integrated Manufacturing (CIM). Therefore the question shoud not be that of the short term costs of implementing a non-significant numbering system, but that of the long term costs of not implementing one.

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References

Carlson, J. G. H., "Item Identification and Classification in Management Operating Sytems", Journal of Production and Inventory Management, American Production and Inventory Control Society (1971).

Carlson, J. G. H., "Ongoing Control: The Data Entry Process", Computers in Manufacturing, Vol. 4, Auerbach Publishers, Pennsauken, NJ (1983).

Cullinet Software Inc., "CIMS, Concepts and Facilities", Revision 0.0, Mass. (1983).

Elliott, Paul M., "Nonsignificant Part Numbering: The Better Choice for MRP", Journal of Production and Inventory Management, American Production and Inventory Control Society (1985).

Groover, M. P., Automation, Production Systems and Computer Aided Manufacturing, Prentice-Hall, Inc. (1980).

Ham, I., "Introduction to Group Technology", Technical Report MMR 76-03, Society of Manufacturing Engineer, Dearborn, Mich. (1976).

Harhalakis, G. and Khan, R., "Cost Savings--The Role of Part Numberin Systems", Proceedings of the Sixth Annual Meeting of the American Society for Engineering Management, Portland, Oregon (1985).

Harhalakis, G., "Engineering Changes for Make to Order Products. How and MRP II System Should Handle Them", Submitted to the Journal of Engineering Management International.

Harhalakis, G., "An Integrated Production Management System for Engineered Equipment", Ph.D. Thesis, University of Manchester Institute of Science and Technology, UK, May 1984.

Jackson, James J., "Use the Computer to Assign Your Part Numbers", Twenty-Eighth Annual Conference Proceedings of the American Production and Inventory Control Society, Toronto (1985).

MIL-STD-28, "Drawing Titles, Approved Method of Assignment", Office of the Assistant Secretary of Defense (Supply and Logistics) (1958).

Orlicky, J., Material Requirements Planning, McGraw-Hill, Inc. (1975).

Sedgwick, H.K., "Item Identification in Design, Manufacture, Operations and Logistics", Raytheon Corp., Lexington, Mass.

Table 1. Item master data storage and processing in MRP II

Type of Data	MRP II Subsystem or module	Transaction Type
Item description	Bills of Materials	Item Master data
Item classification (e.g., make, buy, GT codes, etc.)	Bills of Materials, MRP, Routings	Engineering data, manufacturing data, purchasing
Material specifications	Bills of Materials, Routings, Purchasing	Engineering data, manufacturing data, purchasing specs.
Next Assembly	Bills of Materials	Product Structure
Gozinto (Goes into)	Bills of Materials	Indented implosion
Storage location	Inventory Control	Bin number and location
Cost or price	Product Costing, Purchasing	Item cost data
Substitutability	Bills of Materials	Material catalog
Drawing number, size, and type	Bills of Materials	Engineering data
Unit of measure	Bills of Materials	Item master data
Revision level	Bills of Materials	Engineering change data
Item effectivity (by date, lot number, contract number) and validity	Bills of Materials	Engineering change data

Figures

1. Engineering Data Maintenance Transaction.

2. A list of self-validated numbers produced by the part number generation program

3. Sample on-line session with part number validation routine