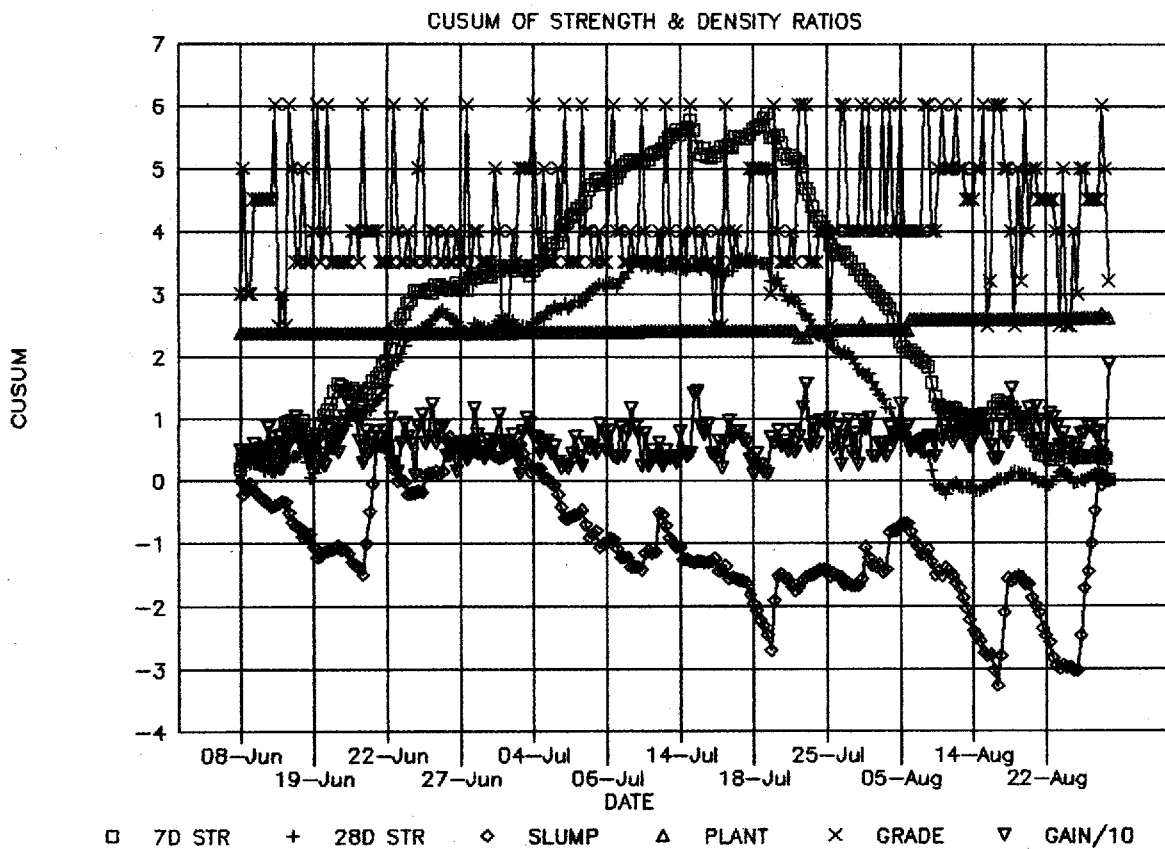


COMPUTERIZED CONCRETE QC USING SPREADSHEETS AND CUSUM GRAPHS

by Ken W. Day



Compilation 13

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Computerized Concrete QC Using Spreadsheets and Cusum Graphs

by Ken W. Day
ACI Compilation 13

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All articles were prepared for *Concrete International* by ACI member Ken W. Day, a concrete consultant from Croydon, Victoria, Australia. A former academic and structural engineer, he has been contributing articles to ACI since 1959.

Preface

The ACI Compilation Series offers an opportunity to gather together material previously published in Institute periodicals as a compact and ready reference on a specific topic. The material in a compilation does not necessarily represent the opinion on an ACI technical committee—only the opinions of the individual authors. However, the information presented here is considered a valuable resource for readers interested in the subject.

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Evaluation of Results of Tests

Used to Determine the Strength of Concrete

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INTRODUCTION

These articles were written largely during 1987 and so are no longer the latest versions of the system described. However, they are still relevant today because they were not intended to provide readers with a ready-made system to copy and use as it stood. Rather, the purpose was threefold. One objective was to assist the non-computer-literate reader to learn to use Lotus 123. A second was to present new techniques of quality control and the third was to show how Lotus could be used to implement these techniques.

It is likely that large numbers of ACI members will be freshly embarking on the use of computer spreadsheets for years to come. It is certain that the "new techniques" of QC, while now more developed and more solidly established, have yet to spread outside the most innovative 1% of the concrete industry. They are no longer new to leading theorists but they are yet to come to the serious attention of the majority of potential users.

If an individual wishes to learn from scratch how to use a computer and to go on to develop their own QC system, these articles should at least halve the time and effort involved. It is of course possible that the newly reinvented wheel will be a better wheel, or will at least fit better into its appointed place, but it should be realized that its cost (of several thousand hours for a complete system) will not be competitive with the purchase of a ready-made system.

This publication is therefore commended to the readers as a textbook on the use of Lotus 123 and on available techniques of concrete quality control. The first few articles will enable the rapid production of an elementary control system which is at least more effective than most of those in current use. The implementation of the more sophisticated techniques in the later articles is better handled by a compiled program (the author uses Borland "Turbo C"). Such a program runs very much faster and is much more bullet-proof and easily learned. However, it does not show its workings to the user and so is less educational.

The latest trends in concrete QC/QA appear to be for it to be largely left in the hands of the producer but with detailed reporting, availability of data and incorporation of a small proportion of independent duplicated tests so that users can assure themselves at minimal cost that the concrete is under effective control. The situation has been completely transformed by the availability of computer batching systems which accurately report the actual as-batched quantity of every ingredient of every truckload. While such data has been available as a print-out for over a decade now, what is new are systems which make efficient use of it. This has very significant implications on the necessary sampling rate for conventional testing because it is now known to what extent each sample is truly representative of the whole spectrum of concrete produced. In effect, the strength of the (unsampled) weakest truckload of concrete produced can be calculated. A further transformation is wrought by bringing forward the age at which strength is measured to 24 hours or less without the use of conventional accelerated curing and by extending this technique to the determination of in-situ concrete strength. The technological basis of all these developments is presented in this series of articles but their actual implementation in computer programs has been developed substantially since their publication.

K.W. Day
June 1991

CHAPTER 1

Your First QC Spreadsheet

A computer spreadsheet is like a very large sheet of paper ruled into rows and columns but with an important difference. Each intersection of a row and column forms a box called a cell. Each cell can contain either:

- A piece of text.
- A numerical value.
- A formula, the answer to which is a numerical value.

The sheet can be set up with columns titled using the text facility. For QC, each row will represent a single batch of concrete from which several test specimens may have been made and on which several tests such as slump and air content may have been carried out.

The important difference between a spreadsheet and a sheet of paper is seen when a formula is entered in a cell. The formula does not appear in the cell, only the numerical answer to the formula, but the formula can be seen (and revised) at the top of the screen when the cursor is positioned over the cell containing it. The formula will refer to values already, or subsequently, entered in other cells on the spreadsheet.

Another important difference is that the computer can print out all or any selected portion of the spreadsheet, and can also graph the data.

Selection of equipment and spreadsheet

There is by now an almost infinite variety of hardware and software available. The instructions given here relate specifically to IBM-compatible computers and to Lotus 1-2-3 software, since these are the most widely used. The techniques described can be used on many other computers and spreadsheet systems (some of which may be even better) but there may be minor differences in detailed instructions. Most of the techniques are available on Lotus 1A but some minor aspects require Release 2.01. The supplementary enhancement program Lotus HAL also adds slightly to convenience, but its availability will not be assumed here.

Lotus comes with an excellent instruction manual and tutorial program which provide much more guidance than is practicable here. In keeping with the assumption that the reader may have no previous experience with computers or statistics, a few of the following paragraphs are devoted to absolute basics. The Lotus manual and tutorial should be consulted for more detail.

Capacity of computer

There are two kinds of capacity:

One is the working memory or random access memory (RAM); the other is the filing memory, often as hard disk capacity (if the computer has a hard disk, which is a large internal data storage device). Memory capacity is measured in bytes: 1K (Kilobyte) = 1,000 bytes; 1MB (Megabyte) = 1,000,000 bytes.

If the computer does not have Lotus 1-2-3 built in, then it will occupy a substantial amount of the RAM (about 120K).

The smallest useful memory for a QC spreadsheet is 100 to 150K, therefore the smallest RAM you should consider is 256K if this also has to accommodate Lotus 1-2-3. The author did much of his initial work with a computer of this capacity, but it is very limiting.

Hard disks come in a range of capacities from 20M to 60M and larger. A hard disk does not increase the size of program that can be handled, but it does greatly ease and speed the task of filing programs, and reduces the number of occasions on which you will feel suicidal having just "lost" data or a program that took several hours to key in.

High capacity on a hard disk is therefore very well worthwhile, even though its total absence will not prevent you doing very extensive QC.

The instructions given here relate specifically to IBM-compatible computers and to Lotus 1-2-3 software. The techniques described can be used on many other computers and spreadsheet systems.

For serious commercial use the smallest computer capacity that should be considered is a 640K RAM and a 20MB hard disk. Such a capacity is adequate for analysis excluding batch quantities and can be extended without discarding the existing computer by the addition of an extended memory board.

A big advantage of the AT-compatible over the XT-compatible is the availability of 1.2MB floppy disks, as opposed to the 360K floppy disk usually used on XTs. The larger floppy disk greatly simplifies back up and storage, although of course a tape back up is even better.

Getting started

We will assume that you have at least read the first chapter of your Lotus manual to avoid duplication of this excellent presentation (version 2; version 1 requires more study). However, it is not necessary to learn all this information before proceeding, since we shall tell you exactly what to do and you will become familiar with the essential parts painlessly through continued use, but the manual should be consulted for more explanation.

Notation

In these articles bold-faced type will be used to indicate what is to be typed or what shows on the screen. Square brackets and bold-faced type will be used to indicate a single key.

F2 means type F, then 2

[F2] means the key marked F2

Enter means type e n t e r

[Enter] means the key marked Enter (or Return, or simply having a bent arrow on it).

Where a space is to be left, the underline key will be used to indicate this, but the underline is not to be typed, only the space. With these exceptions, everything in bold face must be typed and spaces must not be left except where indicated by an underline.

Formulas entered in cells will be referred to as "cell contents." These are displayed at the top of the screen when the cursor is positioned on the cell in question. The numerical value resulting from the cell contents will be referred to as the "cell display." These are displayed in the cell itself.

"Go to" will be used as an abbreviation for "move the cursor to" and "enter XYZ in Z12" as an abbreviation for "go to Z12 and type XYZ[Enter]."

Computers use the asterisk * as the multiplication sign, *not* x. They use the slash / as the division sign.

Correction of errors

If you make an error in entering anything in the computer there are several possible ways of rectifying the situation:

1. If the error is only at the top of the screen (i.e. **[Enter]** has not been keyed) the cursor may be moved to the error using the arrow keys and deleted using the backspace key.
2. If the error is already entered in the spreadsheet move the cursor to it and either key **[F2]** (the Edit key) and proceed as above, or do *not* key **[F2]**, but simply type the correct entry (this will replace the incorrect entry when **[Enter]** is typed).
3. Keying **[Esc]** generally undoes the last move. Sometimes it has to be keyed several times to undo sev-

eral steps before the **READY** indicator appears.

4. **/RE A10..Z13 [Enter]** will erase all entries in the rectangular area bounded by rows 10 and 13 and columns A and Z.

5. **/RE [Enter][Enter]** will erase the contents of the one cell in which the cursor is currently centered.

Note that the backspace key deletes the digit/letter to the left of the cursor, not the digit/letter above the cursor.

Your first spreadsheet

You are now ready to produce your first spreadsheet. Assume you are obtaining results from tests on ready mixed concrete and are taking three test cylinders and one slump test from test samples. One cylinder is tested at 7 days and two at 28 days.

Go to A16 and enter **DATE**, to B16 and enter **DOCKET No**, to C16 and enter **SLUMP**, to D16 and enter **7D**. The computer will beep and refuse to enter 7D. This is because it starts with a number so the computer assumes it is a number and will not accept a letter in the middle of a number. One of the keyboard keys has a single and a double inverted comma on it. These are "text marks." Move the small flashing cursor line to the start of 7D (at the top of the screen) and type the text mark key. A single inverted comma appears in front of the 7 telling the computer it is to be regarded as text; now it will enter 7D in D16. However, it is better to use the caret (the small inverted v) as this centers the 7D in the cell. Enter **^28D1** in E16, **^28D2** in F16, **^MEAN 28** in G16, **^GAIN** in

	A	B	C	D	E	F	G	H	I	J
7										
8				4500						
9										
10										
11										
12										
13										
14										
15										
16	DATE	DOCKET No	SLUMP	7D	28D1	28D2	MEAN28	GAIN	PD28	CUSUM7
17	09-Feb	420835	3.2	3988	5873	5728	5800	1813	145	3988
18	09-Feb	420836	3.2	4133	5945	5800	5873	1740	145	8120
19	10-Feb	420878	3.6	4133	5122	5003	5062	930	120	12253
20	17-Feb	421188	3.8	4458	6122	6033	6078	1620	89	16711
21	17-Feb	421204	3.8	4278	5800	5873	5836	1559	— 73	20988
22	18-Feb	421265	3.8	4495	5945	6090	6018	1523	— 145	25483
23	18-Feb	421267	3.2	5873	7323	7250	7286	1414	73	31356
24	18-Feb	421285	3.2	5438	6670	6815	6743	1305	— 145	36793
25	18-Feb	421292	3.2	5583	7033	7105	7069	1486	— 73	42376
26	18-Feb	421299	3.0	5185	6788	6598	6693	1508	191	47561
10-Jan-89	10:58 AM									NUM CAPS

Fig.1 — Sample spreadsheet.

H16, ^PD28 in I16 and ^CUSUM7 in J16.

Now go to A17. You may enter your own results in A17 to F17 or copy the values from Figure 1.

In the Lotus system the date is entered as a number. The number is actually the number of days since 1 January 1900. The column in which the date appears may be formatted either before or after entering the number in it to display the date in any one of five alternative forms. We shall use/RFD1 (DD-MMM-YY, e.g. 12-Aug-88) or/RFD2 (DD-MMM, e.g. 12-Aug).

Enter (E17 + F17)/2 in G17, + G17 - D17 in H17, + E17 - F17 in I17 and + D17 - D\$8 + J16 in J17.

Now go to D8 and enter a likely average value for the 7-day results. The \$ in front of the 8 tells the computer that D8 is an absolute, not a relative cell address (see later [and your manual]). Now it remains to write these formulae in the next 100 or so rows as well as in row 17. This is not difficult or time consuming.

Go to cell G17. Type /. A menu (a row of words) appears above the row of letters at the top of the screen. One of these words is

Copy. You can move the cursor to it and type [Enter]. Much more simply, just type C, which has the same effect. Now type . (the period) and move the cursor along to J17. All the cells G17, H17, I17 and J17 should now be brightly illuminated.

The top of the screen will now say **Enter range to copy FROM: G17..J17.** Type [Enter]. The bright area contracts to G17 again and the message changes to **Enter range to copy TO: G17.** Type . again, and move across to J17 again. Then hold down the [↓] key. The bright area now extends from G17 to J17 and all down columns G to J. Stop at row 50 — or row 100 if you wish — this enlarged bright area is called a range. Type [Enter]. The bright area disappears and when the indicator in the top right hand corner stops **WAIT** flashing and says **READY** the whole area will be covered with zeros (unless you have already entered some results).

Go to J18. Note that the top line (the cell contents) reads + D18 - D\$8 + J17. The computer has incremented D17 to D18 and J16 to J17 but has left D\$8 unchanged. This is the difference between absolute and relative addresses.

As results are now entered in columns A to F, the zeros will automatically change to show means, gains, pair differences, and the Cusum.

Saving the spreadsheet

In the next article we will explain what conclusions you should be able to reach from this first sample analysis, especially what a Cusum is (it stands for Cumulative Sum), how to do a continuous, automatic, statistical analysis, and how to get Lotus 1-2-3 to draw a graph. But for the present you must know how a spreadsheet can be filed between sessions and how to retrieve it.

Type /. The menu appears again. This time **File** is selected by typing F, then type S (for **Save**). The computer asks for a name to file it under. The name can be only up to 8 letters long, maybe "GRADE3" or "PROJXYZ" or "XYZ3" — but can contain no spaces, colons, dashes, etc. We will simply use "FIG1" so key /FSFIG1 [Enter]. The computer will then save (ie. file away) the spreadsheet — but the question is where? It may be on the hard disk or on the floppy disk (if there is one in the slot).

You can tell the computer where to file the spreadsheet by keying

C:FIG1 or **A:FIG1** or **B:FIG1**. A and B will be the two floppy disk drives (if you have two) and C the hard disk. You can semi-permanently set the drive to be used by typing **WGDD** (Worksheet, Global, Default, Directory) and entering the drive and directory you wish to use, followed by **[Enter]** (eg: **C:123** to save it on the hard disk in directory 123 or **A:** to save it on the floppy disk in drive A).

Retrieving your spreadsheet

Type **/FR** (for File Retrieve). Your filename is probably listed above the row of letters. If it is the only file it is probably brightly illuminated. If there are several, move the cursor to the one you want and then key **[Enter]**. If there is no list of filenames, or the one you want is not there, the computer is looking on the wrong disk. If you put it on drive C and called it "FIG1," key **C:FIG1** and it will be produced.

Try this before entering more than a small proportion of what has been described above, so that if you lose it during initial learning, no serious amount of effort will have been lost.

Future articles

Future articles are planned to cover such topics as:

- Predicting 28-day strength
- Analysing batch quantities
- Checking results against a specification
- Detecting poor testing
- Aggregate quality variations
- Multigrade operation

Plus we would like to hear from you. What are your problems? Have you some smart ideas of your own? Is *Spreadsheet Topics* useful to you?

These are building blocks — not a rigid structure

Feel free to add further columns to the spreadsheet to include any other data you may have. This may in-

clude air percentage, unit weight, concrete temperature, a second 7-day test cylinder, or a 3-day test cylinder. The objective of this series is to demonstrate techniques to use in building your own spreadsheet rather than to provide a complete spreadsheet to be exactly copied.

Some of the author's spreadsheets have as many as 100 columns of data and analysis and automatically draw more than a dozen graphs, each covering up to six variables. Such a system may take two or three days of concentrated effort to set up. But once set up, the staggering amount of calculation involved when new data is entered takes no effort at all, being performed automatically by the computer. Not only can a non-technical typist enter all the new data, they can even be safely left to advise you when a problem arises with the concrete.

However, retain the original spreadsheet as well since we shall use it in subsequent examples. At this stage the spreadsheet should only include results from a single grade of concrete and you may wish to run a spreadsheet for each of several grades. If doubtful whether results belong on the same spreadsheet (eg. the same grade but from different plants or the same grade and plant but using an aggregate from a different supplier) put them on the same sheet but either provide an additional column to record the difference or describe the grades or docket numbers as say "3000x" and "3000y." A later article will show how these results can be extracted from the spreadsheet if necessary and how they can be separately examined even without extracting them.

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CHAPTER 2

Automatic Cusum Graphing

The first article in this series explained how to set up a simple spreadsheet. This article explains five additional techniques:

- Modifying spreadsheet layout
- Providing automatic statistics
- Drawing automatic graphs
- Interpreting a Cusum
- Speeding result entry

Modifying layout

It is very simple to add extra columns or rows to the spreadsheet. Move the cursor to the location where the column or row is required and enter **/WIC** (Worksheet Insert Column) or **/WIR** (Worksheet Insert Row). Then move the cursor to the right or downwards to indicate how many columns or rows are required and key **[Enter]**. After a short delay the extra columns or rows will appear like magic.

This appears clever enough, but the power of the technique is only seen when it is realized that all the formula cell entries have been automatically modified to accord with the new designations of the moved columns/rows. However, beware! There are a few things that do not change. Graph macros (see later)

are one of them: after the change the graph will still be automatically drawn and still have the same legends — but the wrong columns of data will be read into it!

Whole columns of data can be moved around using a technique similar to that used in Part I to copy formulas down the sheet. The data to be moved is similarly highlighted but the initial command is **/M** instead of **/C**. Move the cursor to the top of the column to be moved, type **/M**. (don't forget the period, think of it as nailing down one end of an elastic cursor so that you can then stretch it to cover as many cells as you wish).

Now move the cursor to the bottom of the column and type **[Enter]**. The cursor can be moved using the **[↓]** key but it can be moved more quickly using the **[Page Down]** key. If there are very many rows, it is quicker still to key in the cell address. So column X, 300 rows long, can be moved to column Z by keying:

/MX1..X300[Enter]Z1[Enter]

Either one or two dots can be used between X1 and X300. Z1..Z300 could be keyed instead of just Z1 but it is not necessary.

The differences between the **Move** command and the **Copy** command are:

- **Copy** leaves a copy behind, **Move** doesn't
- Any formulas in the cells moved change when copying and not when moving
- Any formulas elsewhere on the spreadsheet *referring to* the cells moved change when moving but not when copying.

Convince yourself of this. Enter **6** in cell A1, **+A1*2** in B1, and **+B1-2** in C1. Move the cursor to B1, type **/C[Enter]**. Go to B2 and type **[Enter]**. A1, B1, and C1 all read as they did before (6, 12, and 10) and on moving the cursor to them are seen to contain the same formulas. However B2 reads 0 and contains the formula **+A2*2**.

Now repeat, but using **/M** instead of **/C**. B1 is now empty, B2 reads **12** and contains the formula **+A1*2**, C1 still reads **10** but the formula in C1 is now **+B2-2**.

Text does not change as it is either moved or copied (which is why a graph [or any other] macro does not change — it is text).

B7: [W10]

READY

	B	C	D	E	F	G	H	I	J
7									
8			4500	< replace by D\$12					
9	MAX>	3.8	5873	7323	7250	7286	1813	191	0
10	MIN>	3.0	3988	5122	5003	5062	930	73	-3053
11	NUMBER>	10	10	10	10	10	10	10	10
12	MEAN>	3.42	4756	6262	6229	6246	1490	120	SCALE FACTOR
13	STD DEV>	0.32	658	636	664	648	233	39	1
14									
15									
16	DOCKET No	SLUMP	7D	28D1	28D2	MEAN28	GAIN	PD28	CUSUM7
17	420835	3.2	3988	5873	5728	5800	1813	145	-769
18	420836	3.2	4133	5945	5800	5873	1740	145	-1392
19	420878	3.6	4133	5122	5003	5062	930	120	-2016
20	421188	3.8	4458	6122	6033	6078	1620	89	-2314
21	421204	3.8	4278	5800	5873	5836	1559	73	-2792
22	421265	3.8	4495	5945	6090	6018	1523	145	-3053
23	421267	3.2	5873	7323	7250	7286	1414	73	-1937
24	421285	3.2	5438	6670	6815	6743	1305	145	-1255
25	421292	3.2	5583	7033	7105	7069	1486	73	-429
26	421299	3.0	5185	6788	6598	6693	1508	191	0
10-Jan-89 11:00 AM								NUM CAPS	

Fig.1— Sample spreadsheet.

Columns may be interchanged by creating a new column, moving an existing column into it, replacing it with another existing column, moving the first column into the space vacated by the second, and then deleting the surplus empty column using the 'Worksheet Delete Column' command **/WDC[Enter][Enter]**.

After carrying out these exercises you can save the results by typing **/FSMYSST~** to file them under the title "MYSST". You can then retrieve the original FIG1 by typing **/FRFIG1[Enter]** and continue with the next section.

Automatic statistics

The author's practice is to automatically provide statistics at the top of all columns (it is easier to do all than only some). The first row used for data in this example is 17, leaving the top 16 rows for headings and statistics.

In Fig. 1 columns A and B contain dates and docket numbers and C contains the first data (say slump). Move the cursor to cell C9 and type

@MAX(C17..C116)[Enter]

Now go to C10 and type

@MIN(C17..C116)[Enter]

Now to C11 and enter

@COUNT(C17..C116)

To C12 and enter

@AVG(C17..C116)

and to C13 to enter

@STD(C17..C116)

The top of column C will now show the maximum, minimum, total number, average (mean), and standard deviation of all the values entered in the column (except that if there are more than 100, replace C116 by C216 or other appropriate number).

Now go to C9 and type **/C.** and move to C13 and type **[Enter]**. Type . again (still in C9, to which the cursor will have returned automatically when you typed **[Enter]**) and go to say Z9 and type **[Enter]**. After a short delay the same statistics will appear at the top of every column from C to Z. Of course you see the answers (numbers) and not the formulas. When there is no data the answer is **ERR**, except the cells in row 11 read 0.

Of course some of this data will be useless and can be removed by the 'Range Erase' command **/RE[Enter][Enter]**. In Cusum columns, average and standard deviation

have no meaning, but maximum and minimum are still useful. Cell J12 should be labelled **SCALE FACTOR** and any desired number can be entered in J13 and used (see later) to alter the relative scales of several graphs.

Rows 12 and 13 will probably contain an annoying number of decimal places. This can be overcome by going to D12 and entering **RFF0[Enter]D12..113[Enter]**. You may also wish to go to C12 and enter **RFF2[Enter][Enter]** to set C12 to two decimal places.

Automatic graphs (using macros)

The whole Lotus 1-2-3 system is menu driven, i.e., you can proceed by making selections from menus (at the top of the screen) without needing to remember things. Graphs are no exception. By starting with **/G** a graph menu is obtained and can be followed almost without prior knowledge. However, although simple, the process is painfully slow and you will not feel like repeating it after entering each day's results.



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A	B
~/GRGTLX	~/GRGTLX
A17..A56	A17..A56
~A	~A
D17..D56	J17..J56
~B	~B
G17..G56	K17..K56
~NC	~NC
A1	A1
~OCFGBQSS4~LA	~OCFGBQSS4~LA
7D STRENGTH	7D STRENGTH
~LB	~LB
28D STRENGTH	28D STRENGTH
~TF	~TF
PROJECT XYZ	PROJECT XYZ
~TS	~TS
GRADE PQ STRENGTHS	GRADE PQ STRENGTH CUSUMS
~TX	~TX
DATE OF CAST	DATE OF CAST
~TY	~TY
STRENGTH (psi)	CUSUM
~GBQV	~GBQV

NOTE: Only rows 5,7,17 & 21
have been altered
FROM A to B

The solution is to use a macro. A macro is a series of keystrokes entered on a spreadsheet as text and then activated at some future time by simply pressing two keys — rather like prerecording a message on a telephone answering device.

A macro can be entered in a single cell anywhere on a spreadsheet (out of the required workspace!) but is very indigestible (hard to follow and edit) in this form. My practice is to use a series of cells in a vertical column:

Go to a column (say column AA, which follows Z) off the end of the area you wish to use as spreadsheet.

Go to AA1 and enter ^A (we will call this macro 'A') (see Fig. 2).

Go to AA2 and enter ' (a text mark inverted comma) followed by /GR-TLX (Graph Reset, Type: Line). This erases any previous graph settings in the computer memory and tells it to get ready to draw a linear graph of which the X range will be

The X range is actually entered on the next line, in AA3. It is usually the date, usually in column A, so enter A17..A56.

Go to AA4 and enter ~A. This means [Enter]A (~ is called a 'tilde' and means [Enter] in a macro). The [Enter] actually refers to the X range entry A17..A56 but it is more convenient to put it on row 4. The A says that the next entry will be the A range.

Now go to AA5 to enter the first data range (the A range). Say this is to be 7-day strength and is in column D. Enter D17..D56.

Go to AA6 and enter ~B. Then go to AA7 and enter the second data range, say 28-day mean

strength, in column G. Enter G17..G56.

Up to six ranges (A to F) can be entered, but for the example we will use only two. Also, the number of results would normally be 100 or 200 (so the ranges entered would be A17..A116 or A17..A216).

Go to AA8 and enter

~OCFGBQSS4~LA

This tells the computer that you require the graphs to be displayed in color (if you have a color monitor) as symbols connected by lines. The symbols will be displayed at the foot of the graph with a legend. SS4 says only show the date every 4th result (otherwise they will become an illegible blur). Different numbers can be substituted for 4 — you may need to use 10 or 20 if you use 100 or 200 results. LA tells the computer to label the 'A' range symbol as whatever you next enter.

Go to AA9 and enter '7D STRENGTH (note the text mark before the 7).

Go to AA10 and enter ~LB. As before, the tilde refers to the label in AA9, but it is more convenient to combine it with the next line.

Go to AA11 and enter '28D MEAN STRENGTH.

Go to AA12 and enter ~TF. This

says that the next entry is the main title.

Go to AA13 and enter **PROJECT XYZ** (or any other title you wish to use).

Go to AA14 and enter ~TS. (Next entry is subtitle).

Go to AA15 and enter **GRADE PQ STRENGTHS.**

Go to AA16 and enter ~TX. (Next entry X axis label).

Go to AA17 and enter **DATE OF CAST** (or you may wish to use docket or sample number).

Go to AA18 and enter ~TY. (Next entry Y axis label).

Go to AA19 and enter **STRENGTH (PSI).**

Go to AA20 and enter ~GBQV (which says entries complete, display graph).

The macro is now complete but is not yet activated. It is an order you have typed out but not yet issued.

Now go to AA2 and type /RNC/A[Enter][Enter] (Range Name Create 'A' cell AA2).

Now move the cursor to a blank cell anywhere (just in case something goes wrong!), hold down the [Alt] key and type A.

This invokes (activates) the macro. The screen will go blank and after a very short delay a graph



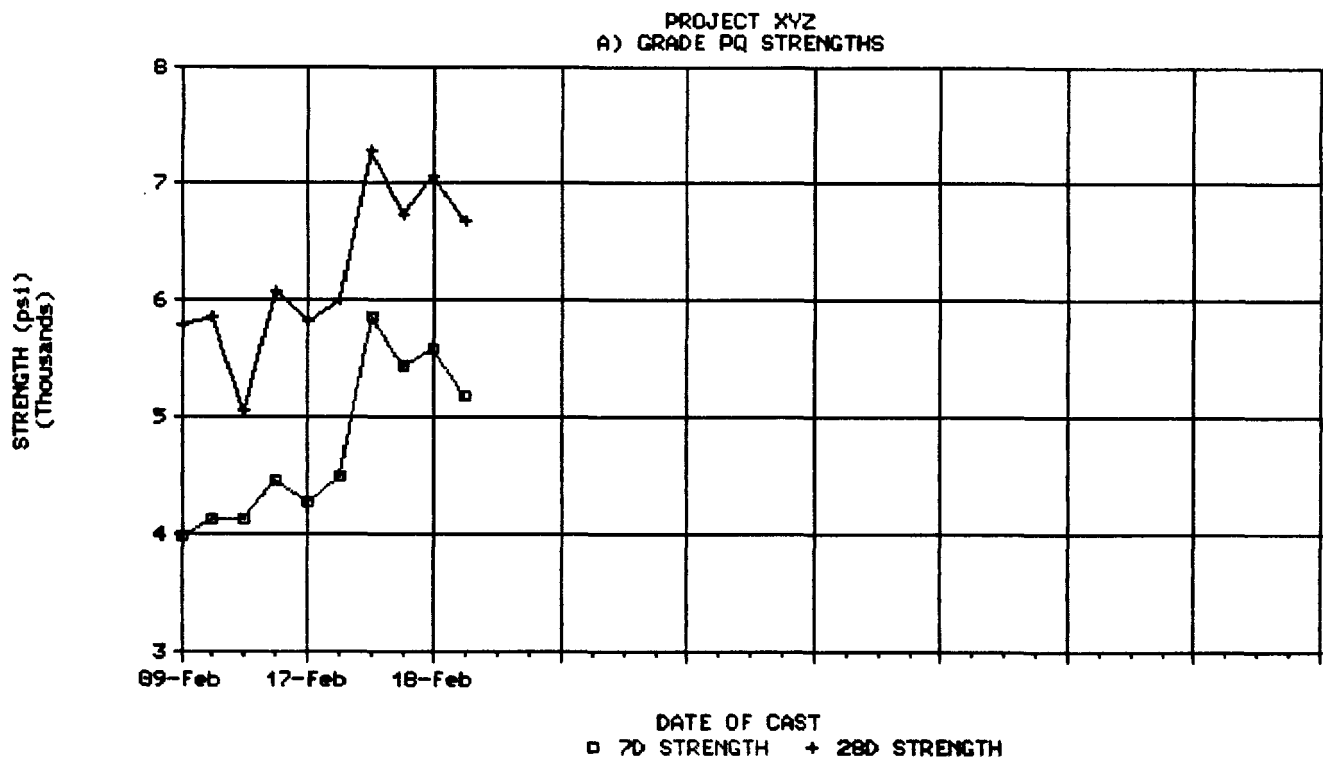


Fig.3— Cusum graph A.

will be drawn on it — a fascinating experience which never ceases to amaze and impress onlookers.

It will assist your understanding of what the macro is doing if one time you type out the macro 'live' (without the text mark preceding the /G), thereby following the key-strokes on the menu at the top of the screen.

Hitting any key now removes the graph and returns to the original display of the spreadsheet. However, Lotus has not yet forgotten your graph and the menu at the top of the spreadsheet indicates that it is awaiting your instructions as to what to do with it. Typing **V** (view) will cause it to reappear. Typing **Q** will leave the graph program. Typing **S** will instruct the computer to save the graph on disk or in its RAM. The screen will prompt **filename**. Key **FIG2** or whatever else you wish to call it. If you want the graph filed on the hard disk, key **C:FIG2** (the hard disk will be drive C). If on the floppy disk, key **A:FIG2** or **B:FIG2**. If just **XYZA** is keyed, the default setting will be acted upon. **.PIC** will automatically be added to the filename by the computer to indicate that this is a graphics file. Such a file cannot be

recalled to the screen but is ready for printing. In a future article printing the graph on paper will be covered.

The real value of the macro layout used is seen when a second graph is required. Go to AA2, type /C.; go to AA22 and type **[Enter]**. The whole macro should be brightly illuminated by the cursor before **[Enter]** is keyed and the cursor will contract again to AA2 when **[Enter]** is keyed.

Now move to AB2 and type **[Enter]** again.

Alternate lines of the macro comprise operating instructions and text or ranges on which the instructions operate. Therefore a completely different graph can be produced by changing the alternate lines of text and spreadsheet data ranges without disturbing the operating instructions.

A second graph macro identical to the first appears in column AB. New data ranges, titles and legends can now be inserted (by going to each in turn and using the **[Edit]** key or simply overwriting) without disturbing all the basic instructions on alternate lines.

For your second graph, select the column J of Cusums you created in

Part I (i.e., enter **J17..J116** in AB7) and label the Y axis **Cusum** (in AB19). The Cusum graphs are probably the most important part of your QC System.

It will be necessary to go to AB2 and create the second graph macro (macro B) by typing **/RNC/B [Enter][Enter]**. This graph will then be seen when **[Alt] + B** is typed.

Now see if you can add a Cusum of the 28-day mean strength as shown in Fig. 2 (use column K for the Cusum and AB9 for the graph instruction).

Interpreting a Cusum

A Cusum can be interpreted from a column of figures, but the graphical form is much more useful.

The main point to grasp is that position has no significance on a Cusum graph. Only the slope of the graph has significance. Specifically, changes in slope are the points of interest.

A Cusum is a cumulative sum of differences from the initial value (in Part I you entered the approximate mean 7-day result in cell D8 and used it to produce a Cusum column in column D). If the initial value selected continues to be the same

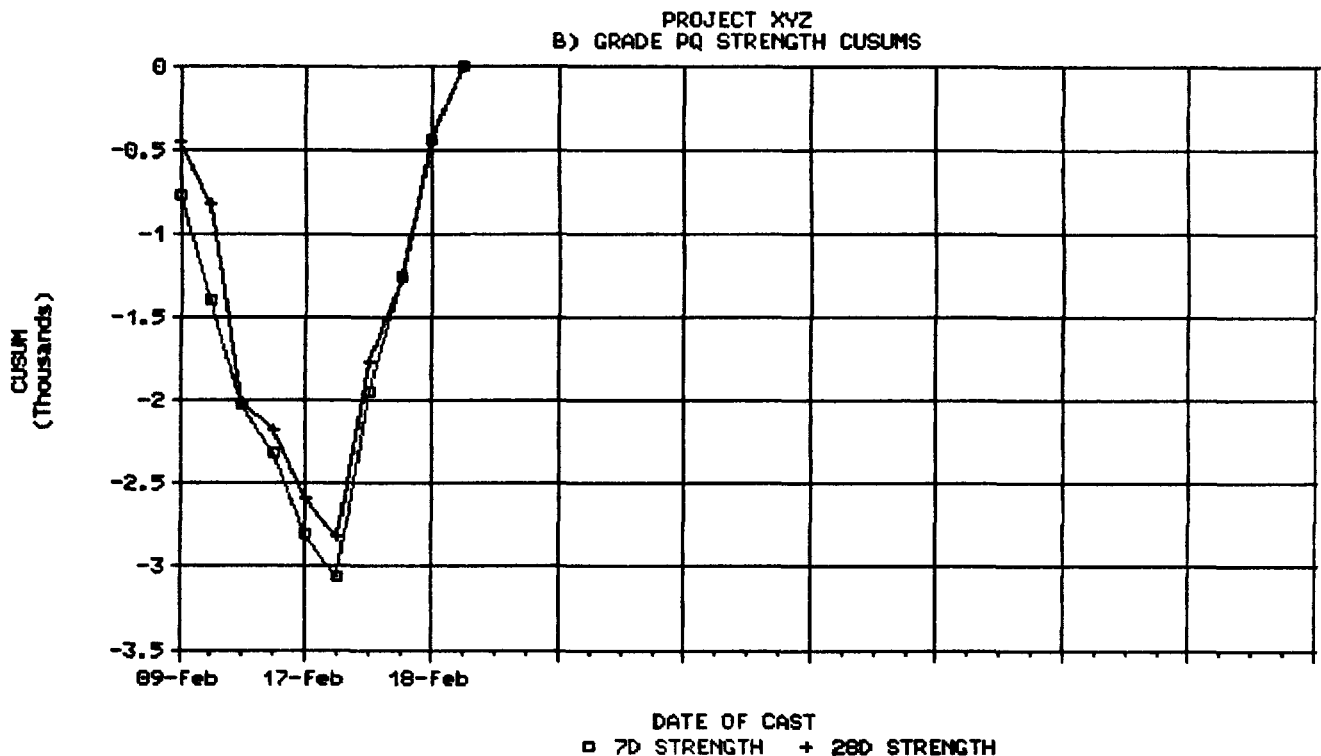


Fig.4— Cusum graph B.

mean then, by definition, on average the Cusum of differences from it must be zero and the graph may be uneven but will be horizontal.

As soon as the mean changes (say by minus 50 psi) each succeeding Cusum will, on average, be 50 psi less than the preceding value and the graph will turn down at an angle given by the change in mean, i.e., after 10 results, the graph will register approximately -500 psi and after 20, approximately -1000 psi. If a single sharp change in mean occurs (which, in the author's experience, is the normal situation) the graph will be straight before and after the change and the point of change will be clearly visible.

Note that the situation is not getting worse as the graph continues to descend. A straight line is a stable mean, regardless of whether the line is horizontal or slopes up or down. If a further strength reduction occurs, there will be a further change of slope.

The whole purpose of a Cusum graph is to reveal these 'change points' and to enable change points in strength to be correlated with change points in slump, or density, or air content — or simply with the

date of delivery of a new truck of cement or admixture, or perhaps with the date you engaged a new testing officer! Truly big brother is watching when the Cusums appear on screen, as will be seen in future articles.

Your Cusum graph probably dives to enormous negative values because it extends beyond the range of results you have entered and so is assuming a whole row of zero strengths. To rectify this, go to J17 and change the entry to **@IF (D17 > 0, (D17 - D\$12) * J\$13 + J16, J16)** and copy this (I/C) down column J. See Part III for the 'conditional entry' **@IF**. Note also the use of the mean result in D12 and the scale factor in J13 (enter this as 2 initially but try changing it to see the effect). The scale factor is used to balance the graph scale to avoid high variation in one variable masking smaller variations in another.

Speeding entries

By now your spreadsheet contains many formulas. Each time you enter a single number on it, the computer recalculates every single one of these formulas. It is therefore not

surprising that it takes a few seconds to do so. If you go on to fill the entire memory of the computer with a large spreadsheet, each entry can take more than a minute.

The solution is to key **/WGRM** (Worksheet, Global, Recalculation, Manual) which switches off automatic recalculation. Your computer will now accept data as fast as you can key it in but you have to remember to type the **[calc]** key (see your manual for where this is, probably **[F9]**) after it is all entered.

Please tell us

Are we going too quickly or too slowly for you? Do you have any problems with your spreadsheet? This series is to help you become proficient in computer QC, and you are welcome to ask for assistance with any problem. Do you have a better way of doing something? We should like to hear about that also.

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CHAPTER 3

Database Techniques

The first two articles in this series explained how to set up a simple spreadsheet, modify the layout, obtain automatic statistics and graphs, interpret a cusum, and speed up result entry. This month's topics include:

- Coping with missing results
- Database techniques
- Monitoring testing quality

Missing results

It would be relatively easy to operate spreadsheet control if there were never any missing results, but this is rarely the case. Probably by now you have already experienced problems with missing single 28-day strength results upsetting the mean, gain, and pair difference columns.

Lotus 1-2-3 is able to accept a conditional entry in the form "If x, then y, otherwise z." Applying this to the mean of a pair of results in columns E and F, go to G17 and enter:

@IF(F17>0,(E17 + F17)/2,E17)

This copes with both results missing or only one result missing (providing you wish to give the remaining result the status of pair average).

Another way of achieving the same objective might have been to enter **@AVG(E17..F17)**. Lotus will ignore empty cells, so this type of formula would provide an average for one or one hundred results. But if there are no results an error message is given, which will upset subsequent attempts to analyse the means. It would be satisfactory, but perhaps cumbersome, to enter:

@IF(E17>0,@AVG(E17..F17),0)

Note that in the first example F17 was selected for the criterion, and in the second E17. Also note that the @ sign is essential — it tells Lotus to look up the very next word in its list of special functions.

The pair difference takes us another step, because we have to be sure both results are present:

**@IF(E17>0#AND#F17>0,
@ABS(E17 - F17),0)[Enter]**

Here we have used the absolute value of the difference, which is needed to obtain an average pair difference in the "top of the page" statistics covered in the first article. We could have used:

**@IF(E17>0#OR#F17>0,
@AVG(E17..F17),0)[Enter]**

for the average. This would have coped with a missing result in column E when there is still a result in column F, but it seems an unnecessary complication.

Database techniques

The column of means will now contain some zero values where results are missing. Lotus does not include blank cells in its averages, but it does include zero values unless otherwise instructed. This brings us to our first glimpse of the very powerful and important world of database techniques. (Lotus 1-2-3 is so called because it can do three things: spreadsheet, database, and graphing).

The concept of database extraction is that of selecting from a table of numbers only those rows which have (or which do not have) a particular characteristic. We shall use the technique in later articles for such things as separating different grades of concrete or the characteristics of different trucks (or drivers), for printing out lists of any problem results and for delivering on-screen warnings of problems.

For the moment, we simply wish to exclude zero results in a single column. Three things are needed to do this:

- A database

- Selection of a column in the database
- A criterion

The first two are easy as the database is only a single column. But there is a trap: one row and only one row of headings must be included in the database. So if the database is to be column G and the first row of data is row 17, the database is specified as G16 to G116, column zero. The "G116" in the example below could be G66 or G216 as appropriate, but if G17 is written instead of G16, the instruction is completely ignored. It would be possible, but pointless, to specify the database as A16 to G116, column 6 (note that the first column of a database is column 0, not column 1).

The criterion must now be established. Rows 6 and 7 will be convenient for this. Cell G6 must contain exactly the same as G16. It is not enough to look the same to you. If one cell contains "MEAN" and the other "MEAN " (i.e., MEAN followed by a blank space), they will *not* be regarded as identical by the computer and the criterion will be inoperative. The only safe way, which fortunately is the easiest way, is to copy (IC) the G16 entry into G6. Usually all of row 16 is copied into row 6, just in case (Fig. 1). Now enter **+ G17>0** in G7.

The computer has now been instructed to accept only entries greater than zero from the column headed by whatever is in G6. It remains to alter the entries in rows 9 to 13 as follows:

@DMAX(G16..G116,0,G6..G7)

@DMIN(G16..G116,0,G6..G7)

@DCOUNT(G16..G116,0,G6..G7)

@DAVG(G16..G116,0,G6..G7)

@DSTD(G16..G116,0,G6..G7)

The easiest way to do this is to write the first entry (G6) as:

B5: [W10]

READY

	B	C	D	E	F	G	H	I	J
5									
6		SLUMP	7D	28D1	28D2	MEAN28	GAIN	PD28	CUSUM7
7						1	1	1	
8			4500	< replace by D\$12					
9	MAX>	3.8	5873	7323	7250	7286	1813	191	0
10	MIN>	3.0	3988	5122	5003	5062	930	73	-3053
11	NUMBER>	10	10	10	10	10	10	10	10
12	MEAN>	3.42	4756	6262	6229	6246	1490	120	SCALE FACTOR
13	STD DEV>	0.32	658	636	664	648	233	39	1
14									
15									
16	DOCKET No	SLUMP	7D	28D1	28D2	MEAN28	GAIN	PD28	CUSUM7
17	420835	3.2	3988	5873	5728	5800	1813	145	-769
18	420836	3.2	4133	5945	5800	5873	1740	145	-1392
19	420878	3.6	4133	5122	5003	5062	930	120	-2016
20	421188	3.8	4458	6122	6033	6078	1620	89	-2314
21	421204	3.8	4278	5800	5873	5836	1559	73	-2792
22	421265	3.8	4495	5945	6090	6018	1523	145	-3053
23	421267	3.2	5873	7323	7250	7286	1414	73	-1937
24	421285	3.2	5438	6670	6815	6743	1305	145	-1255
10-Jan-89	11:03 AM								NUM CAPS

Fig. 1 — Sample spreadsheets.

@DMAX(G\$16..G\$116,0,G\$6..G\$7)

This can then be copied into the other four rows and DMAX altered to DMIN, DCOUNT, etc., using the Edit key. The \$ tells the computer not to change what follows when copying it to another cell. Without the \$, the second line would copy as:

@DMAX(G17..G117,0,G7..G8)
and be quite useless.

It is also essential *not* to put the \$ in front of the G (i.e., \$G\$16..\$G\$116). This would work so far but would defeat the next move, which is to copy these formulas all along the top of the sheet using:

/CG7..G13[Enter]G7..I7[Enter]

Note that the heading in G6 is *not* copied in this way but as:

/CG16..J16[Enter]G6..J6[Enter]

In some cases there will be genuine zero values which you do not wish to exclude (e.g., in gains and pair differences). In these cases the formula creating the pair difference can be set to any desired default value (e.g., 0.001):

Enter into I17 and copy down from I17 to I116.

**@IF(E17>0#AND#F17>0,
@ABS(E17 - F17),0.001)[Enter]**

The database can now be set to ignore only the value 0.001 in column I by entering **+I17<>0.001**. All values for MEAN greater or less than 0.001 will be accepted, including zero, but the 0.001 results will be rejected. GAIN can be handled in similar fashion, but in this case negative values must not be discarded or reversed, so **@ABS** should not be used.

Quality of testing

It is probably not until you start using Cusum that you will realise just how difficult it is to test concrete well. It is the author's experience that a low result is just about equally likely to be due to bad testing as to bad concrete. Around the world millions of dollars are spent investigating, and even removing and replacing perfectly satisfactory concrete because the testing was defective and nobody knew how to establish this to the satisfaction of the supervising engineer.

The best criterion of testing quality (compression testing, that is) is the average pair difference which you have just set up above. If your testing is really excellent, your average pair difference will not exceed

0.5 MPa (72.5 psi). Up to 1 MPa (145 psi) is reasonable, but if you have pair differences greater than this then poor testing is costing you a lot of money in depressed mean strength and inflated variability. (If it is your concrete and someone else's testing, we suggest that you give a copy of this article to the supervising engineer.)

The author's experience is that if two organisations are testing the same concrete and one has a pair difference of d and the other of $d + x$, then the mean strength found by the latter will be lower than that of the former by an amount sometimes as high as 2 or 3 times x . The apparent variability of the concrete will also be increased.

It is not simply a matter of setting up things correctly in the first place — performance must be continuously monitored, and the Pair Difference Cusum graph is the ideal tool. Try using a new inexperienced testing officer and see what happens to this graph (whilst it is likely to turn up, it could just as likely turn down because the new officer is trying harder!). If you have several testing officers, do not do this in secret, put a graph on the wall

