Ancient censuses

How did the ancient Babylonians feed their people? How did Florence Nightingale transform nursing? How did the allies make D-Day a success? How do you know that smoking may kill you? The answers are all "by using statistics". To accompany the timeline overleaf we present a selection of great statistical landmarks of the past – moments when statistics changed history.

The first censuses

The history of statistics is the history of people trying to understand themselves. We may never know how someone, somewhere, decided that gathering information about people and what they did would be helpful to the development of mankind, but the idea has lasted and has served humanity well. However it happened, it most certainly was related to the old task that governments have been carrying out for centuries, indeed for millennia: counting their population and its production.

The census became one of the first common statistical practices in the ancient world. It is almost as old as civilisation and government. Even the name is related to government. The word "statistics" comes from the eighteenth-century German word *Statistik*, which meant the analysis of data about the state.

The first recorded census was probably undertaken by the Babylonians around the year 3800 BC. These first statistical collections were an essential guide to the rulers, allowing them to estimate how much food they needed to find to feed their population. Census records were recorded on clay tiles; an example is in the British Museum.

Some 1500 years later the Egyptians used censuses to work out the scale of the labour force they would need to build their pyramids. They also used the information to plan how they would share out the land after the annual flooding of the Nile – government data is versatile. Censuses took place in other ancient civilisations – Persia, Greece and India among them. The information was mostly for tax collecting or for raising armies.

A well-known book, written around the fifth century BC and still in print, has a census at the heart of it. The Book of Numbers, the fourth book of the Bible, is named after the counting of the Israelite population during the Flight from Egypt. It tells how God ordered Moses, in the wilderness of Sinai, to number those able to bear arms: "Take ye the sum of all the congregation of the children of Israel, after their families, by the house of their fathers, with the number of their names, every male by their polls; From twenty years old and upward, all that are able to go forth to war in Israel: thou and Aaron shall number them by their armies." A total of 603 550 Israelites were found to be fit for military service.

Censuses appear elsewhere in the Bible. In Chronicles and the Book of Samuel, King David is punished with three days of plague in the country for taking one. The best known, of course, is the census in Luke's Gospel which caused Mary and Joseph to travel to Bethlehem to be counted. Luke was referring to the census carried out by Roman governor Quirinus in Judea in AD 7.

The Romans conducted censuses every 5 years. It was the main duty of the official known even then as the censor – one of the highest dignities of the state, second only to the consuls. In the city of Rome every man had to present himself at a special building in the Campus Martius and give his name, his father's name, his age, and details of the land, slaves and cattle that he owned; rules were laid down about how their value should be estimated – estimation remains a key element of statistics.

Only men were counted directly; each was asked "declaring from your heart, do you have a wife?" Single women and orphans were represented by their guardians, were entered on separate lists and were not included in the total. The census was used, among other things, to determine who belonged to the social class of equestrians or knights – who were entitled to a state-supplied horse.

Penalties for not attending were severe. Under the republic, any man who did not present himself at the census could be sold as a slave.

In China during the Han Dynasty a census took place in the year AD 2. It recorded a population of 59.6 million, the world's largest at the time. The Yellow River and Huai River valleys had the largest population densities; Chengdu, the largest city, had a population of 282 147. This is the earliest census for which complete data survives; even by today's standards it is considered to be fairly accurate.

Censuses have been identified in ancient Mexico: a twelfth-century migration of different tribes into the valley of Mexico counted 3.2 million individuals arriving in what would later be Mexico City. The fifteenth-century Inca Empire had a unique way to record census information: lacking a written language, they used a system of knots on strings.

Ancient censuses were remarkable social and organisational achievements. Their takers probably assumed they were accurate; increasing sophistication has increased understanding of the possible errors in censuses – even today it is almost impossible to count everyone – but has not always increased their accuracy. The 2001 census of the UK had 390 000 people recording their religion as "Jedi knight" from *Star Wars*. It is not an error that would have occurred to the ancients.

Carlos Gómez Grajalez

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Florence Nightingale

"To understand God's thoughts we must study statistics, for these are the measure of his purpose."

So wrote Florence Nightingale in her diary. We remember her for her work in the Crimean War but she was far more than the Lady with the Lamp who nursed soldiers. She was a passionate statistician; and she was perhaps the first person to use statistics to influence public and official opinion. She used statistics to change society.

Her interest started young. At the age of 9 she was organising data from garden fruits and vegetables into numerical tables. Born to wealth and society, she met as a girl such intellectual giants as Charles Babbage. At 20 she was receiving, at her own request, two-hour lessons from a Cambridge-trained mathematician. She found the sight of a long column of figures "perfectly reviving".

She went out to the Crimean War, to Scutari in Turkey, in 1854. She found that not even the numbers of soldiers entering the hospitals, or leaving them – alive or dead – was known. From the first she kept meticulous records. The data she collected was the evidence that saved lives.

Her statistics changed her own understanding. She arrived believing that inadequate food and supplies were the problem. But deaths began to fall only in March 1855, after a Sanitary Commission arrived at the Scutari hospitals. They did what she could not do alone: they flushed the sewers, removed putrid animal carcasses that were blocking the water supply, replaced rotten floors and improved ventilation. Almost immediately, the mortality rate dropped from 52% to 20%. Lack of sanitation, she realised, had been the principal cause of deaths.

Back in England she met William Farr, Britain's foremost statistician at the time. They collaborated for twenty years. She wrote *Notes on Matters Affecting Health, Efficiency, and Hospital Administration of the British Army* – it was an 850-page book rather than notes, and was filled with statistics of mortality and causes of death. Her data revealed that during the war more had died from disease than in London during the plague of 1665. "Oh my poor men who endured so patiently", she had written: "73 percent in eight regiments dead during six months from disease alone". Even had the army fought no battles it would have been annihilated, by disease, within two years. She determined to reform things.

She started from the top – with Queen Victoria. But Her Majesty's eyes would glaze over, she feared, at her long list of numbers. "Statistics should be the driest of all reading", said Farr. Nightingale knew better.

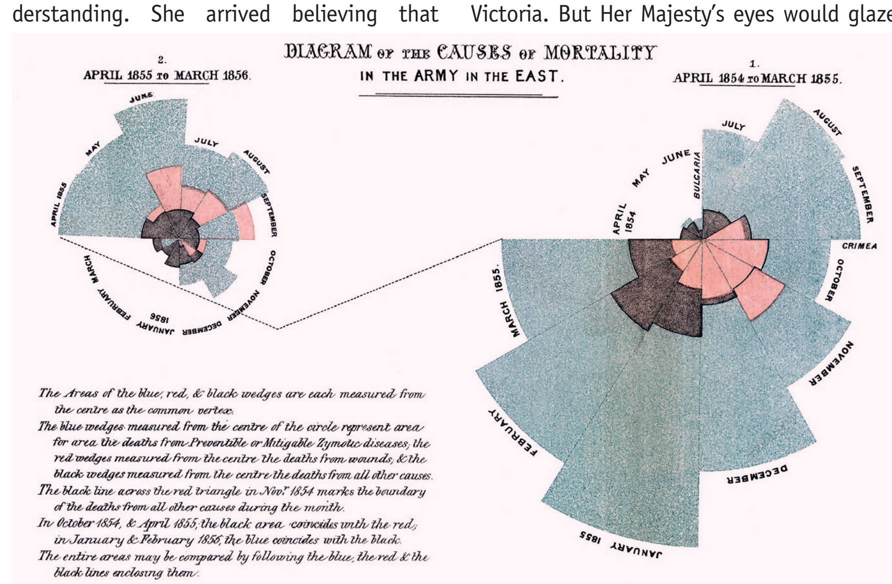
She devised ways to make the statistics interesting – to show them to the world she pioneered graphs and visualisations. Many were printed in colour, even then. A bar chart showed soldiers' deaths as thin red lines, each twice as long as the black line for civilians: soldiers were dying at twice the rate – even when they were in England, so insanitary were their barracks. She devised a circular graph, known as the Nightingale rose or (inaccurately) as the coxcomb, an early version of the pie chart. Hers compared deaths from wounds with deaths from diseases; the "disease" areas were many times larger. The War Office showed no interest, but public outrage, informed by her graphs, forced it to take action. Basic sanitation in military hospitals began to become the norm.

She reformed healthcare at home as well. She investigated London hospital statistics; it was impossible to draw conclusions because each hospital recorded things differently. She proposed that the same forms be used in all hospitals: an apparently small change, but one that allowed treatments to be compared, the best ones identified – and lives saved.

In 1858 Florence Nightingale became the first female fellow of the Statistical Society of London, now the Royal Statistical Society. She became the first overseas member of the American Statistical Association. "Her statistics were more than a study, they were indeed her religion", wrote another founding figure in statistics, Francis Galton. "Florence Nightingale believed – and in all the actions of her life acted upon that belief – that the administrator could only be successful if he were guided by statistical knowledge."

The legend is of the lady with the lamp treading the wards. Her greatest achievement came later. Modern healthcare owes as much to her use of statistics as to the care she gave to the sick. She conveyed statistical truths to ordinary people. She used statistics to change people's minds.

Eileen Magnello



Florence Nightingale's polar area diagram of the causes of death during the Crimean War (1858)

great moments in statistics

Doll and Hill link lung cancer and smoking

It has been one of the great revolutions in public awareness: most people know that smoking causes cancer. Sixty years ago smoking was almost universal among UK men. Today around 20% are smokers. Back then, smoking was advertised as good for health. Now cigarettes cannot be advertised at all.

Today office smokers in Britain have to huddle in doorways during tea-breaks to indulge; transport and pubs are smoke-free. It began, as far as the public are concerned, with a short journal article published in the summer of 1954.

The chief medical statistician had observed an extraordinary increase in lung cancer during the 1940s. It was happening more in men than in women. Suggested causes included pollution from car exhaust fumes, from the dust of tarred roads (Doll's own initial belief), from gasworks, industrial plants and coal fires. But Switzerland had largely clean, unpolluted air – and lung cancer had risen similarly there. And, though this was still the era of the London smogs, air pollution in Britain had actually decreased.

One thing that had increased was cigarette-smoking. Soldiers in the First World War had been issued with cigarettes; before that tobacco had been usually smoked in pipes or cigars – and therefore not inhaled. Cigarettes became ubiquitous only in the twentieth century, when their production was mechanised. By the 1950s smoking was so common that nearly 80% of the adult male population smoked. The vast majority of their cigarettes were without filter tips.

Some pre-war German researchers had made the connection, but had gone unnoticed. Richard Doll and Austin Bradford Hill were the two who publicly established the link. Hill was already the leading medical statistician of his day. He had pioneered randomisation in medical trials – the gold standard method today for assessing new treatments. Ironically, he had had lung disease himself: he became a statistician after tuberculosis during the Great War made him unfit to train as a doctor. His work had brought him a CBE, and Fellowship of the Royal Society; he was a pillar of establishment medicine. Richard Doll, on the other hand, was a fiery agitator – so fiery that he was almost ostracised by some in the medical community. A committed communist, he had treated marchers' blisters on the Jarrow hunger-marches of the 1930s and resigned from the Party only in 1957, and then as much because of Soviet espousal of bad science as because of their tanks crushing the Hungarian uprising. But his passion for evidence-based medicine made Hill choose him as a collaborator. Their paper appeared in the *British Medical Journal* of June 26th, 1954. It was just five pages long; it could be understood by anyone.

It turned the usual way of doing things upside down. Hill had already looked at Londoners with lung cancer and compared them with Londoners with stomach cancers or diabetes; more of the lung cancer patients smoked. That, like almost every medical trial, looked backwards at people who already had the disease. The new study instead looked forward, at people who were *going to get* the disease. They called it a "prospective study" and it was so new and unusual that they had to give the dictionary definition of "prospective" in a footnote: "Characterized by looking forward into the future."

They turned something else upside down as well. Usually doctors do trials on patients; Doll and Hill did their trials on doctors. They wrote to every doctor in the land – 53 000 of them. They sent each one a short questionnaire.

It was a clever idea, because doctors are (a) interested in health (88% of them (47 000) filled in and returned the questionnaire) and (b) easy to keep track of. (Even today many patients in clinical trials simply disappear halfway through.) And in those days very many doctors smoked.

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They called their questionnaire in old-fashioned language a "questionary". It had just five questions. It asked whether the doctor currently smoked, had ever smoked, and, if so, whether a lot, or a little, or just occasionally. It took them and a secretary a year to open all the envelopes. Then they sat back and waited for some of those doctors to die.

Young doctors are obviously unlikely to die very soon. Doll and Hill could not afford to wait 40 or 50 years to complete their experiment. So they excluded doctors under 35 from their analysis. In the course of things, over the next 29 months a few of the others died.

To be precise, 789 of them died; 35 from lung cancer, the rest from other causes (apart from one complicating case whose lung cancer contributed to but did not cause his death – data is never as clear-cut as you would like.) Out of their 47 000 live doctors very roughly one-tenth had never smoked, a third smoked a little, a third smoked more, and a quarter smoked a lot. If smoking and cancer had nothing at all to do with each other, you would expect the 35 who died from lung cancer to be divided up in the same proportions.

They were not. You would expect about 3 lung-cancer deaths among the non-smokers: there were none. You would expect around 8 lung-cancer deaths among the heavy smokers: there were 13. The heavy smokers died from lung cancer at more than the expected rate. It was a small sample: their 57 000 prospects had been whittled down to just 35; but it was still statistically significant.

They were careful in their paper *not* to say that smoking causes lung cancer. They *did* say that there was a "real association" between smoking and lung cancer. It could be that stress causes cancer, and that stressed people take up smoking. It could be that air pollution causes cancer, and that dwellers in (polluted) cities happen to smoke more than country folk. Such confounding explanations can be multiplied without end – and were, by some tobacco companies, which waged and funded campaigns of disinformation for the next two decades.

Nevertheless Hill and Doll gave a strong hint: they pointed out it was not just smoking or not smoking that mattered: instead the *more heavily* people smoked, the *more likely* they were to get lung cancer – a finding which, they said, "makes it possible to attach a simple interpretation to the results". Doll himself, a smoker for 17 years, gave up because of the findings.

Not everyone accepted their results. The government downplayed them, perhaps because 14% of government revenue came from tobacco tax. "The evidence is statistical only" (is there any other kind?), said the Minister of Health, at a press conference at which he chain-smoked throughout. Even the great statistician R. A. Fisher was unconvinced, perhaps because he was an inveterate smoker who kept his pipe firmly clenched between his teeth even when he went swimming. He felt that susceptibility to lung cancer, and the desire to smoke, were more likely to be determined by genes, so he set about researching the smoking habits of identical twins.

Hill and Doll carried on with their doctor-watching. Ten years on, 4597 of their male and 366 of their female doctors had died – a much more powerful statistical sample. By that time they could report that the death rate of cigarette smokers from lung cancer was 13 times the rate for non-smokers, and for heavy smokers it was over 30 times.

Perhaps as significant, by that time about half of their original doctors who had been smokers had given up. The following year, cigarette advertising was banned on UK television. In the US, TV cigarette advertising ended in 1971. Public opinion was on the turn. Strong evidence presented clearly had overcome the most powerful pressure-groups and vested interests. It was statistics that had wrought the change.

Robert Woods

The German tank problem

Imagine that you want to know how many taxis there are in London or New York. Every licensed taxi carries a number. You obviously will not see all the taxis in town, but in the course of five minutes you might see four. Suppose that one bears the number 17, one is 250, one is 337, one is 591. Can you estimate how many taxis there are in all?

It will have to be more than 591. (We assume the numbers start at 1.) Might it be as high as 1000? If so, we might have expected one of our numbers to be in the 700s or higher. It probably will not be as high as 10 000: if it were, we would have expected to see some four-digit numbers in our sample.

In fact a statistical formula gives the most likely answer. It is shown in the box.

The only time we really want to know how many London taxis there are is when it is raining. There was a time, though, when a similar problem was of desperate importance.

In 1944 the Allies were preparing for D-Day. They needed to know how many German tanks they might face on the Normandy beaches. Specifically, they were worried about the new Mark V "Panther" tank; it was heavier, with a bigger, longer gun, and it was feared that it could outperform the American Shermans. It had recently been encountered in Italy. The hope was that, since it was new, there would only be a few of them in France.

Hope was not enough. Planners had to know exactly how many Panthers there were.

Tanks, like taxis, carry numbers – dozens of them. They have chassis numbers, engine numbers, gun-barrel numbers. And some of those numbers run in sequence, from 1 to however many tanks have been made.

Tanks, though, are harder to catch than taxis. The allies had captured just two Mark Vs: one in Sicily, one in Russia. Would two be enough to do the taxi trick and work out how many tanks there were in all? The problem was handed to American statisticians.

The chassis numbers did not help. They knew, from other tanks, that chassis were made by five different manufacturers with big breaks in the number sequences. Gearboxes, on the other hand, were numbered in an unbroken sequence from 1 on up. Even so, two is a pretty small sample. Still, the formula gave an answer.

Fortunately, tanks have bogie wheels that support the tracks; the bogie wheels have rubber tyres; the tyres are made on a mould; and each mould bears a number that also gets moulded onto the tyre. Nor do moulds last for ever; the analysts asked British tyre manufacturers how many tyres they would expect a mould to make before it is replaced with a new-numbered one. More fortunately still, each Panther tank had eight axles, and each axle had six bogie wheels, making 48 wheels per tank.

They applied the taxi formula, suitably adjusted, to their 96 differently numbered bogie tyres. They came up with an answer; and it agreed very well with their gearbox answer. The Germans, they estimated, were producing Panther tanks at the rate of 270 a month. This was many more than the D-day planners had expected. The assault plan was revised. The landings succeeded.

And were the estimates accurate? After the war the exact figures were found. In February 1944 276 Panther tanks had been produced. The estimate had been 270. The statisticians had got it almost exactly right.

Julian Champkin

> The formula to estimate the total number of taxis (or tanks) is
>
> $N \approx m - 1 + m/k$
>
> where m is the highest serial number that we have spotted and k is the number of taxis or tanks we have seen. In our example, of four taxis with 591 as the highest serial number, this gives an answer of 738 taxis in London. Spotting more than four taxis would improve our estimate; and more complex formulae, giving Bayesian probability distributions, are available.

Panzer III "Panther". German Federal Archive