

Watchmaking

and the

**American System of
Manufacturing**
(revised)

by

Richard Watkins

Other translations, transcripts and books by Richard Watkins:

- Berner, G.A. and E. Audetat: *Pierre Frederic Ingold 1787-1878*, (1962) 2008
- Berthoud, Ferdinand and Jacob Auch: *How to make a verge watch*, (1763 and 1827) 2005 (ISBN 0-9581369-6-3) (with E.J. Tyler)
- Borsendorff, L.: *The history of a watch followed by a conversation on the horology industry between Mr Trottevite and Mr Vabien*, (1869) 2007 (ISBN 978-0-9581369-9-0)
- Buffat, Eugene: *History and design of the Roskopf watch*, (1914) 2007
- Camus, C.E.L. and J.I. Hawkins: *A treatise on the Teeth of Wheels*, (1837) 2007 (corrected version of the Google Book copy)
- Crespe, François: *Essay on repeater watches*, (1804) 2006 (ISBN 978-0-9581369-8-3)
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- Japy, Frederic: *Patent for 5 years for various horological machines*, (1799) 2006
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- Saturday Magazine: *Manufacture of Watches in Switzerland*, (1842) 2008
- Waterbury Watch Company: *Ali-Baba and the Forty Thieves*, (1889) 2005
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- Watkins, Richard: *Mechanical Watches, an Annotated Bibliography of Publications since 1800*, 2004 (ISBN 0-9581369-5-5)

These are available from www.watkinsr.id.au

Articles by Richard Watkins:

- Berthoud, Harrison, and Lalande: A Near Myth*, NAWCC Bulletin, No. 359 (December 2005): pp. 773-743.
- Jacques David—and a Summary of “American and Swiss Watchmaking in 1876” with Emphasis on Interchangeability in Manufacturing*, NAWCC Bulletin, No. 350 (June 2004): pp. 294-302.
- Confabulations - A Humorous Look at Complications*, NAWCC Bulletin, No. 367 (April 2007): pp. 163-172.
- The above are also available from www.watkinsr.id.au
- Practical Watch Collecting, a Manual for the Beginner*: Part 1, NAWCC Bulletin, No. 375 (August 2008): pp. 429-447; Part 2, NAWCC Bulletin, No. 376 (October 2008): pp. 569-577; Part 3, NAWCC Bulletin, No. 377 (December 2008): pp. 679-690; Part 4, NAWCC Bulletin, No. 378 (February 2009): pp. 35-44.
- The Repeater: Part 1, The Continental Quarter Repeater*, NAWCC Bulletin, No. 378 (February 2009): pp. 73-89.

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Introduction

The purpose of this monograph is very simple. It is to propose that the term *The American System of Manufacture* be defined as the *manufacture of machines by unskilled labour*. That is, I want to shift the focus away from mass-production, factories and interchangeability, the three corner-stones of all explanations of the system that I have read.

I expect this the definition of the American System of Manufacture could be explained in just a few pages if it were done in the context of clock-making and armory practice. But because my main interest is watch-making, I wanted to examine it in that context, even though it occurred many years later. This is not surprising because the manufacture of watches is far more difficult than the manufacture of clocks and guns. Not only are components of the machine much, much smaller, but the accuracy with which the machine must function, and hence the accuracy of the parts, is significantly greater.

The generally accepted view is that the successful application of the American System of Manufacture to watch-making took place at the Boston Watch company between 1850 and 1856, under the auspices of Edward Howard and Aaron Dennison; that is

*“the use of machinery to turn out interchangeable parts for watches on a large scale was first achieved in America by the Boston Watch Company”.*¹

However, some writers claim that it was applied earlier by other makers, some of whom were not Americans. And also, there are different opinions as to what was actually achieved.

In contrast, I will argue that the system was not successfully applied until 1857, after Royal Robbins had taken over the Waltham factory.

This monograph is in two parts.

Part 1 examines the conventional definition of the American System of Manufacture and then looks at relevant American attempts at watch-making up to the beginning of 1857; that is, the Pitkin brothers and Dennison and Howard.

Part 2 examines the events at Waltham in 1857 and establishes my alternative definition of the American System of Manufacture. In doing this I also look at the work of Japy and Ingold. I then briefly consider the consequences in later watch manufacturing.

Most of this monograph simply provides a convenient summary of known evidence and interprets it in ways that, to my knowledge, are generally acceptable. However my emphasis is different, the sole objective being to examine watch production and in

particular *rate of production*, for it is rate of production that provides the best clues to company success.

It must be noted that there are significant contradictions and inaccuracies in many sources, and some writers make statements for which there are no apparent provenances. And quite often these views are repeated in later works.

This variety of opinion means that it is necessary to very carefully examine and assess the different claims. More importantly, it is necessary for me to provide detailed and complete justifications for my assertions. To do this I have taken care to do two things:

First, I have tried to provide complete citations, although some repetitions of statements have not been included. The footnotes in this monograph are reserved for the references and can be ignored by the reader unless he or she wishes to check the original sources. Unfortunately too many of these sources fail to provide details of where they derived their information. Sometimes their statements are obviously wrong, but in others the information is credible and useful. However their lack of citations can cast doubt on their reliability.

Second, I have included four appendices which provide justifications for the main points in my argument. This information has been separated out so that the reader can gain an overall understanding without being interrupted by the lengthy and reasonably tedious detail which underlies my research.

Because I expect some readers, like myself, are not Americans, the following map of part of Massachusetts has been included. Until I had seen it I had no idea of the relationships between the principle towns which participated in the early period of American watchmaking.

Richard Watkins

Erratum

Much to my embarrassment I have discovered an error in my description of the two-barrel, eight-day watch made by the Marsh brothers (see page 23) which has been corrected here. The original stated that this watch did not use an extra wheel and pinion when in fact it must. However, this error has no impact on my argument and in that sense is unimportant.

1 Price, page 1.



Part 1: From Cottage To Factory

The Origin Of The Species

The American System of Manufacture is often described in rather vague terms that gloss over and obscure necessary details. It is not that such statements are wrong (most are not), it is that broad generalisations often only express one aspect of the system.

Trowbridge defines the *American interchangeable system* as

"The art of making complete machines or implements, each part of which may be introduced into any machine of the same kind, and especially the adaptation of special tools, by which hand-work in fitting the parts is often entirely avoided".²

He goes on to say that

"it is possible to furnish such machines at low prices only by ... assembling the parts which are required for a complete machine at a single and separate operation".³

In contrast, and in the context of horology, Clint Geller writes that it is

"the development and first practical demonstration of truly efficient mass-production methods for watches".⁴

In fact, implicit in Trowbridge's definition is the need to mass-produce, for the building of many complete machines from parts requires a stockpile of those parts. But the reverse is not necessarily true and mass-production need not inevitably lead to interchangeability. For example, in the late 18th and early 19th centuries, the Swiss and English mass-produced ebauches (rough movements), but the accepted viewpoint is that the products were not interchangeable. And as Buffat points out, even as late as the 1870s Roskopf movements were manufactured in batches of 2,000 movements, apparently mass-production.⁵ But these movements required hand fitting and I would not regard them as interchangeable. So Geller is right in that mass-production is involved, but it cannot be the central, key feature of the American system.

Richard Meibers gives yet a third definition:

*"Industrialization brought all these workers together into **manufactories**, creating a new way of life and what became known as the American System of Manufacture"*⁶

Even though Trowbridge does not say so, also implicit in his explanation of the American system is the use of factories. Wright, in his history and analysis of the development of factories, states that the first

"perfect factory, the scientific arrangement of parts for the successive processes necessary for the manipulation of raw material till it came out finished goods"

was the cotton factory built at Waltham in 1814, which received raw cotton and produced finished cloth.⁷ Such a factory

"is an association of separate occupations conducted in one establishment in order to facilitate the combination of the processes into which most branches of manufactures are divided".⁸

Although the language is archaic, the essence is clear: the effective organisation and control of *multiple trades* under one roof.

But again we have a one-way relationship. A factory need not produce interchangeable parts, but mass-producing interchangeable parts without a factory is unlikely.

It should be noted that the term "*factory*", as used above, means a single, distinct place where *all* processing takes place. As Waldo puts it,

"The American system ... means the establishment of working facilities for the entire manufacture. That everything is made on the premises, not according to the plans or ideas of individual workmen, but under the direct supervision of a company's foreman ...".⁹

This is the model adopted by American watchmakers. In contrast, twentieth century Swiss watchmaking mass-produced watches using interchangeable parts made by a large number of small, independent organisations which were an extension of the previous *établissage* industry. For example, Glasmeier notes that in 1955 there were 2,316 companies, with an average of 22 workers each, and 7,867 home workers.¹⁰ And even large, factory-based companies such as Longines made use of small suppliers and home workers.¹¹ Many of these companies could not be called factories according to the definitions of Wright and Waldo because they did not produce complete watches, making, for example, just balance springs. So the Swiss system differed from the American system in at least this respect.

2 Trowbridge, page 615.

3 Trowbridge, page 615.

4 Geller [1], page 1.

5 Buffat, page 15.

6 Meibers, pages 23 and 31.

7 Wright, pages 539-540.

8 Wright, page 533.

9 Waldo, page 189.

10 Glasmeier, page 200.

11 Marti, pages 194-197.

Finally, also implicit in these views, and sometimes explicitly stated, is the use of *machinery*. Although this may seem obvious, there is a danger that ignoring the obvious may lead to misconceptions. For example, the machinery used by the English cottage industry may have been the same as used by any individual watchmaker; basic lathes and other tools for hand work. So even if they mass-produced interchangeable parts, there could be qualitative differences in the methods and organisation.

Whether such differences are important remains to be considered, but it is necessary that we examine the *type* of machinery used rather than just its mere existence.

Thus Trowbridge is correct in placing the emphasis on interchangeability; it is the fundamental cornerstone upon which the American system is built. However, all four aspects are needed, and so we should define the American system as *the mass-production in a factory of products from interchangeable parts by the use of machinery*. It is this definition, with minor variations, that forms the basis of the analyses by Hoke,¹² Glasmeier and others. Because all four aspects are intimately related, it is almost impossible to discuss one in isolation; any argument must necessarily invoke all because you cannot have one without the other.

So far, I have deliberately ignored a fundamental point.

Implicitly or explicitly, all the discussions of the American system of manufacture are predicated on its originality. Indeed, it is called the *American* system, not the interchangeable system, for that very reason; as Trowbridge says it

*“is, I believe, of American origin”.*¹³

But what is original about it?

Mass-production had been carried out long before the Americans developed it and, irrespective of the method or the results, the Swiss, French and English had successfully mass-produced watch movements by the end of the 18th century. Certainly Japy mass-produced movements, supposedly making at least 40,000 a year in the 1790s with only 50 workers, using machines designed and patented by Japy.¹⁴

Factories existed in England and on the continent which pre-date American factories. For example, those for cotton manufacture and Japy’s watch and clock factory in Beaucourt. To some extent, Trowbridge avoids this problem by defining the American system to be the *“art of making complete machines or implements”*, so excluding cotton manufacture. But the problem still remains: there is little or nothing original to the Americans.

Machinery had been developed by Japy, Ingold and others prior to or contemporaneously with the Americans.¹⁵

And *interchangeable parts* had been used in the 1780s. Rolt points out that interchangeable parts for guns were made by Le Blanc in 1785 and Bodmer in 1806, both in France. Of the latter, it was written

*“Mr Bodmer invented and successfully applied a series of special machines by which the various parts ... were shaped and prepared for immediate use, so as to insure perfect uniformity”.*¹⁶

This, with the omission of the word “American”, is just what I have defined above. Also, Japy achieved a degree of uniformity that we must regard as interchangeable if we are also to accept the claims put forward for the Pitkins and others.

About the only thing we might be left with is the *combination* of all four aspects in a single entity. But even the originality of this is dubious to say the least, as the factories of Bodmer and Japy fit this requirement. Admittedly, Cutmore notes that Japy’s movements were *“identical”* but the parts were not interchangeable in that they required hand finishing, and after finishing *“the parts would still not be interchangeable”*.¹⁷ But much depends on how the word *interchangeable* is defined. If we follow the example set by Hoke, which I will discuss shortly, then Japy’s movements were definitely interchangeable.

So what we do know is that the very existence of the American system appears to rest on a quick-sand of half truths and its originality in America is dubious to say the least. Indeed, the phrase *the American System of Manufacture* appears to be a mythical creature, a mirage, and the closer we try to get to it, the further away it is, until it vanishes and we are left with nothing.

But this is untenable. The system does exist.

So what are we missing? There is no doubt that *all* the commentators can’t be wrong and there *is* something which sets the American system apart. But it cannot be the conventional aspects of factories, machinery, mass-production and interchangeability.

The Holy Grail

In a TV interview, the famous American economist J.K. Galbraith once said:

“There are some advantages in being right.

You don’t have to change your mind.”

Unfortunately, being right is not that easy! In reality differences of opinion coupled with the ambiguity of most historical information make any sort of absolute rightness impossible. All that we can hope to do is to follow Morpurgo’s advice, that professional historians are

12 Hoke [1].

13 Trowbridge, page 615.

14 Cutmore, page 19, Harrold [1], page 28.

15 Japy, Penny [1].

16 Rolt, page 148.

17 Cutmore, page 20.

“those people who, by the use of documents [and artefacts] and their own intelligence and knowledge, pursue a matter to its core, but not those who blindly repeat the opinions of others” (my insertion).¹⁸

That is, it is necessary to question everything and allow nothing to be taken for granted. For we are at greatest risk of erring when we gloss over what seems obvious, only to find out later that the obvious was in fact obscure. Or the obvious was not obscure, but so generalised as to allow any interpretation and any circumstance to fit. Either way we risk drawing conclusions that are at best unhelpful and at worst wrong.

In the context of the American system, this requires us to carefully examine every aspect of our definition and expose the consequences of different interpretations and choices.

Of the four factors, mass-production, factories, interchangeability and machinery, it is interchangeability that creates the most problems. Mass-production and factories are a question of degree, how much and how big, and achieving some consensus should not be too difficult. And machinery can be examined, categorised and its behaviour specified. But the word “interchangeable” is often used without any attempt to define it, and without specifying what is interchangeable.

Yet interchangeability is the holy grail of manufacture and especially of watchmaking. Finishing and adjusting movements takes a large amount of time, and requires the most skilled and most highly paid of all watchmaking workers. What if parts could be made so accurately that they required no finishing, and they could simply be taken, put in a watch and work? What if parts could be made so accurately that the watch would work without needing to be adjusted for isochronism, temperature and positions?

Hoke is one of the few writers who has defined the term interchangeability:

“In fact, every nineteenth-century manufacturer of complex mechanisms designed these mechanisms to be adjusted at the time of assembly. Thus the interchangeable parts were interchangeable, but only to the degree necessary, the degree stipulated by the design of the product”.¹⁹

And he states, with regard to Waltham:

“Watches were also interchangeable within the confines of this new definition of interchangeable. Most parts ... were completely and fully interchangeable, while some parts were interchangeable until assembly”.²⁰

As he points out

“The segregation of partially finished watches was critically important, because, at certain points in the manufacturing operation, some of the parts of each watch were machined with respect to each other and had to be kept together”.²¹

This weak definition, which forms the basis of Hoke’s book, has been used by many writers. For example, Torrens, with respect to manufacture in Prescott, says

“parts for any particular size of movement of the same maker were interchangeable within the limits set by the condition and the rate of wear of the tools”.²²

And Glasgow, writing about Wycherley’s late 19th century factory in England, states

“the wheels, barrels, and other parts are practically interchangeable in their unfinished state”. (my emphasis)²³

But there are two serious problems with this approach.

First, it is a cart-before-the-horse argument. Parts were *not* made interchangeable “only to the degree necessary”, but as interchangeable as the machines and techniques allowed. And the manufacturing process was dictated by lack of interchangeability and not the other way around.

To take the most extreme case, consider the balance, balance-staff, balance-spring and balance jewels. Hoke says

“As with typewriters, watches required adjusting as an integral part of their manufacture”.²⁴

This is true, but it is true because it was (and still is) *impossible* to make these parts with sufficient accuracy. If that could have been done then the months of laborious testing and meticulous adjustments would have been unnecessary and high quality watches would have been far cheaper.

A clearer illustration of this is the end-shake tool described in Appendix B. We know from Jacques David and others that both the length of arbors (from pivot shoulder to pivot shoulder) and the diameters of pivots varied so much that jewel holes had to be chosen to suit a particular arbor and then set into the plate by a varying amount to suit the arbor length, the latter being done using the end-shake tool.²⁵ Thus the plates were adjusted to suit the arbors, resulting in non-interchangeable arbors and non-interchangeable plates, plates which may have been interchangeable before finishing!

18 Morpurgo, page 56.

19 Hoke [1], page 308, note 5; Hoke [2], page 60, note 96.

20 Hoke [1], pages 262-263.

21 Hoke [1], page 244.

22 Torrens, page 177.

23 Glasgow, page 42.

24 Hoke [1], page 210.

25 David, page 62.

(However, there is some evidence of size variations in plates which suggests that in the early years at Waltham plates may not have been interchangeable.²⁶ This may be because they were manufactured by Scoville in Waterbury, with less quality control, and not in house; although, at least in later years, the dies were supplied by the watch company.²⁷ Out-sourcing plates is sensible, because punching blanks takes very little time. For example, if 50 workers could make 3 watches simultaneously, at about 16 man-days per watch, then the person making the plate blanks would cut out the plates needed for 3 movements, taking less than a day, and then be idle for the rest of the 16-day cycle. So, unless he could perform other tasks he would either have an extremely low, inadequate piece-rate income or be paid for doing nothing. Obviously it would be far better to get Scoville workers to do this work, workers who would have been used to cut out flat brass for a number of different clock and watch companies and so be fully employed.)

Hoke's argument suggests that in 1876 Waltham had deliberately designed watches to use non-interchangeable arbors so that they could be fitted by the end-shake tool. This is patently silly. The end-shake tool was invented only because Waltham could *not* make interchangeable arbors and not the other way around. Indeed, the entire history of American watchmaking is a century long struggle to develop better and better machines to make parts to smaller and smaller tolerances. It was *not* a struggle to design watches for poorly made parts.

If we accept Hoke's definition, and allow final adjustments to be made to "interchangeable" parts, then we must also conclude that Japy made interchangeable parts, because his movements required some final adjustments. And so the Pitkins and the Boston Watch Company were many years after the first mass-production of interchangeable parts. The problem is the vagueness of the statement. How much and what sort of finishing is acceptable?

To make this clear, let me suggest the following: Dogs have legs. Insects have legs. Therefore dogs are insects. This argument is obviously absurd. But consider another example: Interchangeable parts require fitting. In 1763 Berthoud made watches with parts that required fitting. Therefore Berthoud made interchangeable parts. The problem is that dogs are only one type of creature that has legs, and interchangeable parts are only one type of parts that require fitting. There are things with legs that are not insects and fitted parts that are not interchangeable. So, if we set the hurdle too low, then Berthoud made interchangeable parts, but I doubt if anyone would accept this. And if we set the hurdle too high, then interchangeability was not achieved until about the

1930s, 80 years too late. And strictly speaking, complete interchangeability has never been achieved, because even today escapements, balances and balance springs of fine watches have to be individually adjusted.

As another example, I have heard statements about people taking several watches of the same model and grade, mixing up the parts and then successfully re-assembling the watches. One example, cited by Sauers, is

*"if you completely dismantle 100 Hamilton watches of the same model, you could mix up all the parts and reassemble 100 watches that would all run perfectly **with little or no adjusting**. The amazing thing is that you could do this with every model they ever made. I don't know of another watch company that can make this claim".²⁸*

Perhaps Hamilton was far in advance of other American companies, for my own experience has been quite different. I once had two Waltham movements of the same model and grade, but manufactured in different batches a few years apart around 1890. Neither worked, so I tried to build up one good movement using parts from both. I could not. The escapements were not interchangeable and it was not possible to get the balance from one to function with the lever from the other. This surprised me because both were low grade watches and surely the larger tolerances would make it easier, not harder to interchange parts?

But Jacques David makes it clear that reject parts, which were outside acceptable tolerances, were used in low grade movements where larger tolerances were acceptable.²⁹ And so individual fitting was also necessary with those movements, but presumably it was done with less care.

Of course, with a bit of good luck it might be possible to swap parts. But swapping is not enough. Not only must the part fit, but it must fit *within* the required tolerances for the grade of movement, and tolerances vary with the part. It is probably quite easy to physically swap barrel bridges, for example, but unless the holes for the barrel arbor are the correct size we may well find there is too much or too little side shake. An escape wheel or balance is far more critical and our chances of a successful swap are very small; the watch might run, but it is very unlikely that it can be adjusted to the required accuracy. In which case we must regard the swap as a failure. And because balances and balance springs were carefully matched to each other, it is not possible to switch balance springs and expect the watch to function correctly.

²⁶ Price, pages 4-5.

²⁷ David, page 39; Fitch, page 676.

²⁸ Sauers, page 94.

²⁹ David, page 29.

An interesting example of the lack of interchangeability is the use of adjustable banking pins in American watches. Mounting the banking pins eccentrically on screws makes it much easier to set up escapements in which the parts are not interchangeable. And the extra cost and complexity, compared with fixed banking pins, is offset by reduced labour and time. In this case the solution lay not in improved machinery and improved accuracy, but in the design of the watch; just as the Pitkins used screwed in conical bearings to overcome variations in arbors.

The general use of screwed banking pins at Waltham commenced about 1861.³⁰ However, Howard used them on his return to Roxbury.³¹ In addition, Price lists two Boston Watch company movements (Nos. 628 Samuel Curtis and 1351 DH&D) and four American Watch Company movements (No. 1423, PSB made in 1857; Nos. 1871 and 1878 made in 1858; and No. 14748 made in 1859-60. (There is one other odd movement but it dates from 1863.) Making these banking pins would require some sort of machine to form the eccentric pin on the end of the screw and it seems unlikely that these early movements actually had them. However, such a machine might have been built just before the bankruptcy and taken to Roxbury; which would explain Howard's use of them.

Another example of the careless use of "interchangeability" is the standard WW 8 mm watch-makers' lathe. In reality there is little or no interchangeability of parts. I have a collection of split chucks from a number of makers. Despite being *standard* 8 mm split chucks, there is considerable variation in body diameter and length, thread diameter and thread pitch. Some have to be forced into the head stock. At least two have thread diameters so small that the draw bar slides over them. And several cannot be screwed into the draw bar because of thread pitch or diameter problems. Whether lathe makers did not try to make interchangeable parts, or they simply could not do so, is a question that needs to be answered.

The easiest way to tackle the problem of interchangeability is to start with the strictest possible view:

*"The criterion of interchangeability is the ability to choose any part in a pile and insert it in its place, **where it functions without further adjustment or treatment**". (my emphasis)³²*

This definition forbids any manipulation of the part or the place where it is located. Further, the part must not merely fit but must function correctly; by which I mean the fit of the part must be within prescribed tolerances. For example, the end and side shakes for a

balance staff must be neither too large nor too small for the grade of watch; clearly the shakes for a railroad grade watch must be far better controlled than those for a dollar watch. If a part fits but is outside the required tolerances then it is *not* interchangeable.

The advantages of this definition are very important. First, it is fairly easy to decide which parts are interchangeable and which are not. And second, as a consequence, it is easy to define *partial interchangeability* where some pieces are interchangeable and others are not. With this definition we can determine the degree of interchangeability achieved in different places or at different times. But to do this, we need to strip down and accurately measure all parts in a number of movements. As far as I know, no-one has ever done this.

As I have indicated, the majority of writers explicitly, or more often implicitly, weaken this definition in two respects. First, they do not distinguish between partial and complete interchangeability and use the unqualified word irrespective of the degree of interchangeability achieved. Second, they allow parts to be fitted and still regard them as interchangeable. However, no-one specifies just how many parts need to be interchangeable or just how much fitting should be allowed for the word "interchangeable" to be applicable. It is this vagueness that leads to the diverse opinions regarding the Pitkins and other watch manufacturers. By insisting on the strict definition it is possible to remove the vagueness by quantifying the degrees of interchangeability and fitting, and so enable a sensible comparison of different watchmaking endeavours.

Has The Jury Considered Its Verdict?

One serious problem faced by historians is the lack of conclusive evidence. Very rarely do we have the contemporary documents and artefacts to enable a definitive assessment of people and events. Consequently, historical research has much in common with juries. Jurors are presented with incomplete and conflicting information about events and asked to come to a conclusion about what really happened. Like us, they have to work on the *probability* that certain things occurred. By carefully examining the possibility of different explanations, they and we can decide that one view is much more likely than another and so reach a reasonable decision. Unfortunately some people do not understand, or are unwilling to accept, the validity of such a process and they require absolute certainty, which is almost never possible. Others cling to preconceptions or irrational preferences and attempt to justify their decisions by explanations that often have such a low probability as to make them effectively impossible. But the majority of us have at least a vague understanding of the

30 Price, pages 77 and 99.

31 Price, pages 156-157

32 Landes, page 491, note 1.

significance of probabilities and so can reach a sensible, likely outcome, beyond reasonable doubt.

We can liken the various articles and books published over a period time to the opinions of a number of one-man juries. Some provide credible, well argued assessments of the facts and draw likely, satisfying conclusions. A few express opinions that, on careful examination, are simply incredible and unacceptable.

Like the law, later writers often rely upon the precedent set by previous judgements. These people accept some earlier interpretation and repeat it, perhaps with some variations. Which is fine if the person being relied upon got it right, but it is disastrous if an unlikely, unsafe verdict is used. The repetition of such precedents produces myths, statements which, as a result of frequent regurgitation, are taken as true when they are not.³³

The Pitkins provide an interesting example of the need to behave like a jury. There is very little concrete evidence and what we know has been used to produce contradictory statements about what they achieved and their role in the development of the American system. Thus they provide a good place to start our examination of that system.

The most important history of the Pitkins' endeavours is the first, written by Crossman in 1885.³⁴ His account is credible because of the considerable detail of their manufacturing methods and watch designs. The Pitkins manufactured watches in Hartford between late 1838 and late 1841, when they moved to New York. The 5 known watches from this period, with serial numbers from 46 to 164, confirm the generally accepted view that they made at most 200 watches. The Pitkins, together with four apprentices, established themselves in a building, designed and constructed machinery, and then made watches. Although their watches have a number of interesting features, the two most important are the type of pivots (and their holes) and the use of lantern pinions. According to Crossman three different pivot designs were used. However, all of the 4 illustrated watch movements are stated to use the one design of *pivot screw*: conical pivots running in steel, conical holes on the ends of screws. Although he does not explain, Crossman is quite emphatic when he writes

*"the movements were not interchangeable".*³⁵

Twenty years later, Abbott added a little. He quotes Ambrose Webster, who said that the Pitkins

*"attempted to make uniform interchangeable watches".*³⁶

Then we have to wait nearly fifty years for Small to expand our knowledge.³⁷ To a large extent, Small bases

his article on Crossman and Abbott, but he also makes statements which are not derivative. According to him, around 1820 the Pitkins were probably apprenticed to Jacob Sergeant, a master of both silversmithing and watchmaking. However, their later demonstration of watchmaking abilities suggests they learned far more about silversmithing and Sergeant was probably a watch repairer, not maker; a view supported by Crossman. Small believes the

*"Pitkin brothers were the pioneers in the original and revolutionary system of watchmaking which evolved into what has become known as the 'American Plan'".*³⁸

And he goes on to say that

*"there is evidence that [Pitkin] had given some thought to standardization and interchangeability of parts ... That was a natural conclusion, since he was working within the sphere of influence of the Springfield Armory, where Eli Whitney's ideas of mass-production were then receiving their highest fulfilment".*³⁹

But guns are utterly different from watches, both in size and structure. As Fitch shows, the making and boring of barrels is so different that the methods are not applicable. Other than the general principles of presses for lock parts and machining, there is nothing relevant to watchmaking.⁴⁰ It is interesting that Fried states:

*"Even the Civil War helped these young companies: Elgin purchased gun-making machinery cheaply near the end of the war and converted it to watchmaking".*⁴¹

But this is not credible. The only useful machinery would have been general metal shaping tools that could have been used to make watchmaking machinery; the presses, lathes and tools being far too large for manufacturing watch parts. A more startling failure to understand the differences between watches and other manufactured items is that of the 1870 tool supplier to Eterna who used an American automatic nail making machine as the basis for the design of watchmaking machinery. Not surprisingly

*"the new machines, however, functioned miserably!"*⁴²

A number of other writers come after Small. Most base what they write on earlier opinions, adding nothing new. Many of these rely on Crossman and don't need to be considered. And some are not credible. For example, Meibers says the Pitkins

*"manufactured about 500 complete watches with fusees ... prior to 1842".*⁴³

33 Watkins [1].

34 Crossman [1], pages 4-7.

35 Crossman [1], page 5.

36 Abbott [1], page 51.

37 Small [2].

38 Small [2], page 251.

39 Small [2], page 255.

40 Fitch, pages 622-628 and 635-645.

41 Fried, page 10.

42 Brunner, page 21.

43 Meibers, page 59.

But all the early watches made in Hartford had going barrels, as does the New York watch illustrated by Wingate.⁴⁴

The most notable feature is the attitude to interchangeability. At the opposite extreme to Crossman is, for example, Bruton who writes

"they made parts that were interchangeable".⁴⁵

But the majority equivocate, saying the parts were interchangeable but with qualifications. Cutmore, for example, informs us that the Pitkins' watch was

"the first to be made by machine with reputedly interchangeable parts although there is no doubt that the interchangeability would require considerable fitting skills".⁴⁶

The other substantive article is by Wingate, who includes some interesting photographs of watches. Although he relies on Crossman and Small, Wingate has embellished the gaps with statements like:

"After weeks of being confined to bed with a high fever ... he returned to his shop [and] was overwhelmed to see Stratton operating the machinery that stamped out plates for his new watch".⁴⁷

These and other myth-making statements are derived from Rosenberg. But, unlike Rosenberg, Wingate presents them as facts; Rosenberg states at the beginning of his article:

"I have taken the liberty of fictionalizing this meagre data ... where facts are few and imagination must fill in the voids".⁴⁸

Finally, and more recently, Jon Hanson has stated:

*"Several 'experts(?)' have mentioned from time to time that these watches were not interchangeable but this is simply not true. Although these were essentially hand made (actually fitted) and finished, many of the parts **are** interchangeable".⁴⁹*

So it is hardly surprising to find some people state adamantly that the Pitkins produced watches with interchangeable parts whereas others insist nothing they made was interchangeable. It may be that both groups are correct, because they define the word "interchangeable" in different ways and so allow different interpretations. Such a range of opinions can only be resolved if we enter the jury room and decide what, in all probability, reasonable people like the Pitkins actually did. And this is not all that hard if we compare the Pitkins' achievements with our understanding of the American system.

Mass production: In three years the Pitkins and four apprentices produced at most 200 watches. Can this be described as mass-production?

A useful indicator of productivity is the number of man-days required to make one watch, a measure I will consider in detail later. Assuming a six-day working week, or about 310 work-days per year (allowing 3 holidays), the 66 watches per year made by the Pitkins each required about 28 man-days of work. Of course the number of workers throughout this period is not known and the figure could be as low as 19 man-days (four people) and so it seems fair to take an intermediate figure of 23.5 man-days.

To make matters worse, such a figure can only be compared with another, from a different time and place, if the length of the days are the same. For example, Rosenberg suggests the Pitkins had a 12-hour working day.⁵⁰ But later 10-hour days were used, and so the Pitkins took about 34, 28 or 23 10-hour days to make a watch, depending on the number of workers. Clearly the number of man-hours to make a watch would be a better figure, but it is almost impossible to determine and no-one has used this.

What is important is that these figures correspond to those for making watches by hand; although hard to quantify, it seems that traditional watch-making methods took about 25 to 30 man-days per watch.

Factory: 6 people in a small building constitute a workshop, not a factory.

Machines: The only machines that we know they used were presses for plates and other flat work. But, if it took a generous 5 minutes to press out one plate, then the 600 plates and balance cocks for 200 watches could be made in less than 5 days. (The watches do not use a barrel bridge and there are no bridges on the dial plate.) So what did they do for the rest of the three years?

The answer is simple. Marsh notes that

"an ordinary watch movement is composed of upwards of one hundred and fifty distinct pieces, and a careful list of the distinct operations required to complete them all show the number to be over 3,700 or an average of twenty-five operations for each piece."⁵¹

Fitch provides some useful details of different processes.⁵² Harrold suggests a total of 1,200 operations.⁵³ This is based on estimating 8 operations per part, which is too low; for example, making an 8 "leaf" lantern pinion requires at least 40 operations. In Appendix A I provide a third estimate based on the common design of a 7-jewel movement, together with a summary of the different operations involved; it agrees quite well with Marsh's estimate.

But only 12 flat parts can be pressed out of brass and steel, including the wheels, lever and balance. Each of these require a different set of dies and the

44 Wingate, pages 386-391.

45 Bruton, page 184.

46 Cutmore, page 25.

47 Wingate, page 384.

48 Rosenberg, page 582.

49 Hanson.

50 Rosenberg, page 583.

51 Marsh [2], page 13.

52 Fitch, pages 679-683.

53 Harold [2], page 26.

resulting blanks then require considerable further processing.

For example, the under-dial photographs of watches number 46⁵⁴ and 164 (Figure 5), show four circular cut-outs (three eccentric) which do not go through the pillar-plate and so cannot be pressed out. So these have to be turned with the plate held eccentrically on a mandrel or cemented to a wax chuck; remembering that these watches were made long before the versatility of the WW lathe was available.

Even holes passing through plates may not have been punched out. Harrold states:

*"Top plates were stamped with windows in them ... From subtle variations in window shapes, it may be inferred that dies were periodically being re-sharpened, and late watches had no windows at all".*⁵⁵

But periodic sharpening of dies within a run of only 200 plates seems unlikely, and the absence of windows suggests entirely new dies. A far more likely explanation is that the dies cut plain brass disks and the windows were added later by hand.

Anyway, punching parts is the *least* used process, and is insignificant when compared with the 3,688 other operations (or 1,188 if you prefer Harrold's figure) of drilling, turning, wheel cutting, finishing (deburring, smoothing and polishing), and shaping irregular parts, like potences, which cannot be turned or punched out. So the vast majority of the work must have been done using other tools and machines.

Most importantly, the watches themselves are crude. Compared with the hand work of the late 18th and early 19th centuries,⁵⁶ which is the standard of work expected from any apprentice watchmaker of the time, the arbors, pinions, pivots and pivot holes used by the Pitkins stand out as not only unusual, but indicative of serious inadequacies. If the Pitkins were competent watchmakers then it would be much easier and far better to turn arbors from pinion wire on hand lathes than to make tiny lantern pinions and hardened steel screws with conical depressions. As they must have been importing some parts (such as balance springs, mainsprings and dials, which were still being sourced overseas in the 1850s) supplies of pinion wire should not have been a problem. Crossman (repeated by Small) writes that

*"several experiments were tried in order, if possible, to **improve** on the old method in which pivots run in the plates or jewels set in the plates".* (my emphasis)⁵⁷

But what the Pitkins did was certainly not an improvement, and I suspect Crossman was showing their experiments in a better light than they deserve.

Harrold sensibly suggests

*"lantern pinions and screw pivots were logical extensions of clock practice",*⁵⁸

with which the Pitkins would have been familiar and which would be a much more likely source of ideas than Small's suggestion of the Springfield Armory,⁵⁹ although I am not aware of screw, conical holes being used prior to modern, cheap clocks. Harrold suggests they were used to

*"avoid the difficulties and bottleneck of machining pinions from solid" [and to avoid the] "numerous or complicated lathes for performing the many machining operations required to make solid arbors and pinions".*⁶⁰

But this is incorrect, because pinion wire was universally used and, as Berthoud and Auch show, easily "machined" using files and turns.⁶¹ It was still being used in 1856.⁶² Compared to using pinion wire, making tiny lantern pinions, involving drilling small disks and riveting in small wires, would be much more difficult and would require much more skill. It may make sense if the Pitkins' experience led them to make small clocks rather than watches, but it cannot have been easier and certainly was not better.

One fascinating feature of watches number 46⁶³ and 164 (Figure 5) needs to be mentioned here. It is clear from the under-dial views that the cannon pinion and the minute wheel have conventional pinions, whereas I assume the train uses lantern pinions. Why? If the Pitkins had pinion wire and could make a cannon pinion, why didn't they use the same, superior pinions elsewhere? And if they had these skills, why not use superior, conventional pivots? As a juror, I can conceive of no credible explanation other than that they imported the motion work. Although 30 years earlier, David Cooper provides a list of imported tools and material, which includes dials, hands, pinion wire, canon pinions, verges, balances and "*motions*" (which I presume means motion work).⁶⁴ Most if not all was still being imported in the 1850s.

Thus it is probable that, other than presses, the work was done with simple hand tools, such as English turns, mandrels and the like. This view is supported by Small, who quotes Abbott quoting Ambrose Webster:

*"they attempted to make ... all parts interchangeable as far as possible with the **crude** appliances of those days".* (my emphasis)⁶⁵

54 NAWCC [2], page 41 and Hanson.

55 Harrold [2], page 37.

56 Berthoud.

57 Crossman [1], pages 4-5; Small [2], page 256.

58 Harrold [2], page 37.

59 Small [2], page 255.

60 Harrold [1], page 37.

61 Berthoud, pages 30-32, 89-91.

62 Waltham [1], page 144.

63 NAWCC [2], page 41 and Hanson.

64 Cooper, page 27.

65 Small [2], page 255; Abbott [1], page 51.

And other authors also refer to “*simple devices*” and “*crude*” machines. Except for presses, the only other concrete mention of a tool is by Hoke, who suggests they had “*an embryonic gauging system*”.⁶⁶ Although Crossman mentions a gauge for grinding pallets, I suspect Hoke is simply deducing gauges from the supposition of interchangeability. Anyway, gauging has always been a part of watchmaking, and evidence that the Pitkins’ gauges were qualitatively different is needed before we can regard them as significant.

The strongest evidence to support my contention that the Pitkins had no machinery other than presses is the *absence* of any information. There can be no doubt that what the Pitkins did was of great interest to other watchmakers and was talked about. This is clear from the fact that Crossman, writing nearly 50 years later, is able to provide so much detail about their methods, including a precise explanation of how they made the pallets. So we can expect that if the Pitkins used any other novel tools and techniques it would be known and documented. But there is no such information and we can only conclude that there were no other features of their manufacturing process worth talking about.

The importance of this is made clear by my quote from Marsh above and Appendix A, specifying the number and types of operations to make a watch. We know the Pitkins used presses to perform a very small number of operations, but how did they carry out the other processes? How did they drill holes, turn arbors, make screws, pillars, pins, and make lantern pinions? We do not know, but we can be confident that these tasks were performed by conventional methods. Consequently, as Hanson states, the Pitkin watches “*were essentially hand made*”⁶⁷ and not made by machinery.

Interchangeability: The fourth criterion of the American system is interchangeability. Unfortunately there is very little evidence, because (with one exception) the Pitkin watches have not been stripped and examined. But there is simply no reason to suppose the Pitkins achieved any degree of standardisation deserving of the word interchangeability. Most importantly, there are only two reliable statements, by Crossman and then Webster in Abbott; one flatly denies interchangeability while the other makes it sound most unlikely.⁶⁸

The Pitkins’ use of screwed pivot holes was probably a *necessity* and not a *desired* design choice. With them it would be possible to allow for significant variations in arbor length (maybe half a millimetre or more, depending on the thickness of the plates). So built into the design is a way of *hiding* the dissimilarity of the parts. Of course, these conical holes do not help with depthing, and variations in wheel and pinion

diameters would still have to be remedied by re-cutting teeth or altering the positions of holes in the plates. However, the depthing of lantern pinions is far less critical than the depthing of normal pinions, and so there could be some variations in the wheels without it causing problems.

A second feature, mentioned by Small,⁶⁹ is that the early balance pivots were held by a pair of half jewels which could be moved to adjust side shake. This comes from Crossman, but the relevant text and illustrations were omitted from the first edition. Crossman states:

*“At that time, however, they were unable to make jewels of the regular kind, even if they had desired to use them. ... before the regular style of balance jewels were used, they used a device of which a cut is given, much enlarged [Figure 1]. The slides having jewels in them similar to a balance jewel cut in half that would slide up to the pivots, barring side shake necessary for freedom, of course, and then they were set fast by the screw at the bottom. The movement, of which a cut is given [Figure 2], has this arrangement in it also. Just when it was dropped for the regular style of balance jewelling the writer is unable to ascertain”.*⁷⁰

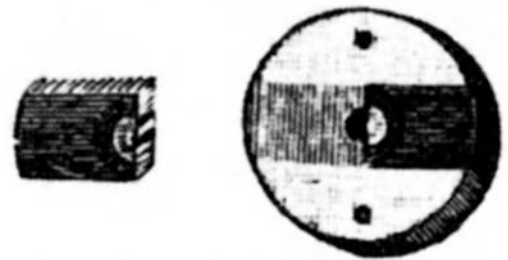


Figure 1 (Reproduced from Crossman [2], page 2)
This method of jewelling is dubious:

- (a) If the balance pivot diameter is smaller than the effective diameter of the jewels and the two jewels are exact halves, then the jewels must be pressed against each other and side-shake depends on how much smaller the balance pivot is. If the jewels are less than exact halves, then the side-shake will be larger parallel to the meeting faces than perpendicular to the faces.
- (b) If the balance pivot diameter is larger than the effective diameter of the two jewels, then there must be a space between the two jewels and side-shake is determined by the corners of the round jewel holes. If these are sharp they will cut the pivot.

If the serial number in Figure 2 is correct, then it is probable that at least the first half of the Pitkins’ production used this form of jewelling.

⁶⁶ Hoke [2], page 63.

⁶⁷ Hanson.

⁶⁸ Crossman [1], page 5; Abbott [1], page 51.

⁶⁹ Small [2], page 256.

⁷⁰ Crossman [2], pages 2-3.

Crossman's explanation for the use of this type of balance jewelling is most likely wrong. At the time jewels were imported and supplies of hole and endstone jewels should have been available. Also, the jewels in Figure 1 could *not* be bought off-the-shelf and would have to be made, and they would probably be harder to make than regular hole jewels. The only reason to use this method of jewelling would be as a poor way of overcoming a lack of interchangeability.



Figure 2 (Reproduced from Crossman [2], page 3)

I am sure the Pitkins did their best, commensurate with their skills and machinery. But their best was to make similar, but not interchangeable parts and produce hand-finished watches. There was still a long road to tread before anything deserving of the name of the American System of Manufacture was produced.

All this is conjecture based on probabilities. If we wish to, we can say 66 watches a year is mass-production; some presses and turns constitute machinery; 6 people in a building is a factory; and parts that need significant finishing are interchangeable. If so, the Pitkins used the American System of Manufacture. But only if we relax our definition even more. Trowbridge defines it as the making of *complete* machines and most certainly the Pitkins did not make balance springs, mainsprings, jewels or dials; all were imported. Should we really accept a process that relied on imported, finished parts? Perhaps we have to, otherwise the Boston Watch Company has to be excluded too; after all, the name the "American Horologe Company"

*"was continued but a few months, it being too suggestive, as they were obliged to send across the water for much of the material they used".*⁷¹

⁷¹ Crossman [1], page 16.

(Dennison denied this name was used,⁷² but Howard stated it was.⁷³)

Even if we feel uncomfortable with this watering down of the concept of the American system, there is nothing to prevent us deciding that the Pitkins created a pre-pubescent version or prototype which evolved into the system during the rest of the 19th century.

I have deliberately avoided mentioning two other important pieces of evidence, because I wanted to focus on what we could learn about the Pitkins from documents. But in addition to the books there are illustrations of five Pitkin watches made in Hartford (numbers 46, 66, 91, 148 and 164)⁷⁴ and one watch has been taken apart and examined.

Figures 3 to 5 show two extant watch movements with serial numbers 148 and 164, Figure 5 being the under-dial view of number 164. Top plate and under-dial views of watch number 46 are available,⁷⁵ but permission to reproduce photographs of this watch was refused.

From these photographs we can see a number of important features:

- (a) The movements were hinged to the case in the English style; both the hinge and the catch are visible in Figure 3 and the catch and its spring in Figure 5.
- (b) The cut-outs in the top plates in Figure 3 and watch number 46 are very different and the differences are far larger than would occur if the one die was re-sharpened. So the cut-outs must have been made by hand.
- (c) In Figures 2 and 4 (and in watch number 46) it appears that the two small screws on the balance cock do not overlap and hold in place a loose collet for the endstone and regulator. This is definitely the case with the bottom endstone in Figure 5. That is, the endstones are fixed directly into the cock and the plate, and the two screws hold the hole-jewel collet (Figure 1). In which case, the two half jewels are held in place by friction, being sandwiched between the collet and the cock or plate.
- (d) The center-wheels in Figures 2, 3 and watch number 46 have conventional pivots in the top plate, whereas there is probably a screw pivot in Figure 4.
- (e) The center-wheels have kidney-shaped cut-outs instead of normal spokes.

⁷² Dennison [3].

⁷³ Howard.

⁷⁴ No. 46, NAWCC [2], page 41 and Hanson; No. 66, Abbott [2], page 25, Small [2], page 252; No. 91, Crossman [2], page 3 and Ehrhardt, page 168; No. 148, Hoke [2], page 62 and Wingate, page 382; No. 164, NAWCC [1], page 12.

⁷⁵ NAWCC [2], page 41 and Hanson.

- (f) The teeth on the center-wheels in Figure 4 and watch number 46 are triangular in shape and nothing like the correct form for meshing with either ordinary pinions or lantern pinions.⁷⁶ The other visible wheels appear to have more conventional teeth.

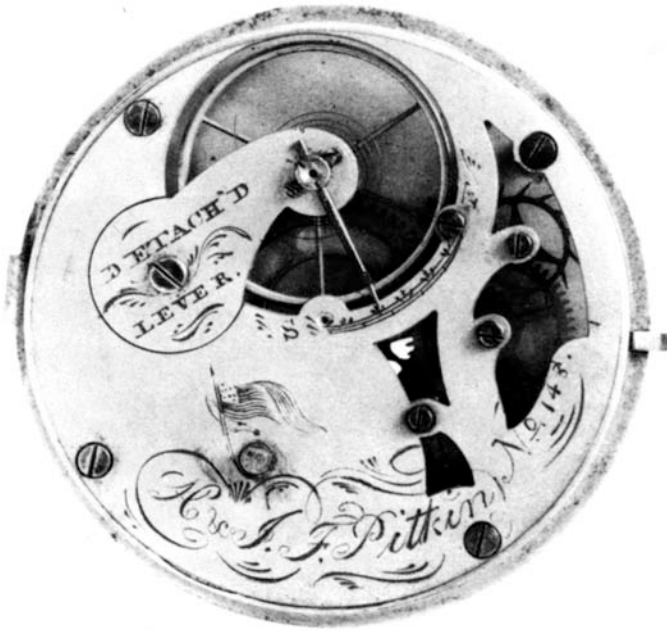


Figure 3 (Reproduced from Hoke [2], page 62)

- (g) In watch number 46, the center, 3rd and 4th wheels have conventional pivots in the pillar plate. In watch number 164 the center and 4th wheels appear to have conventional pivots. This means that for some pivots the only purpose of the corresponding screw pivots is to adjust end-shake.



Figure 4 (Reproduced from NAWCC [1], page 12)

- (h) The escape-wheel and lever have screw pivots in both the top and pillar plates. So these screw pivots can be used to adjust the relative heights of the roller jewel, pallets and escape-wheel teeth as well as adjusting end-shake.

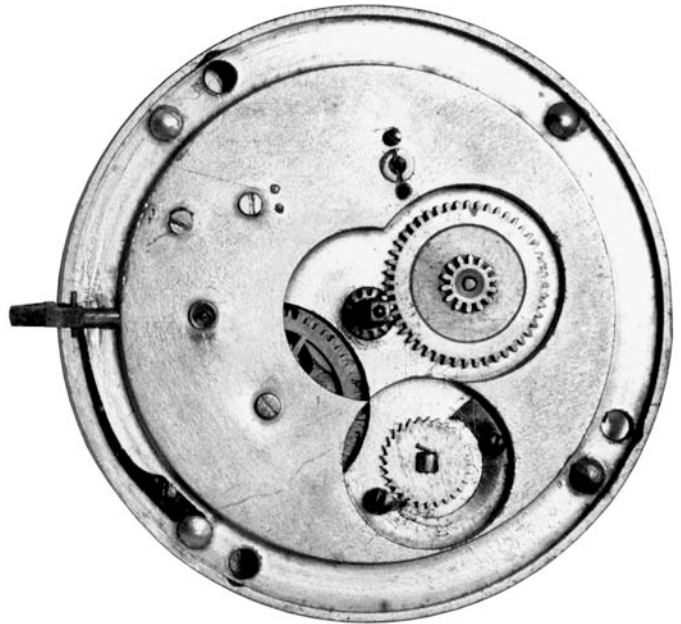


Figure 5 (Reproduced with the permission of David Penney and Don Wing)

- (i) In watch number 46 the barrel ratchet is screwed onto the barrel arbor whereas it is pinned in Figure 5.

In addition, watches 46, 148 and 164 have sub-seconds above VI on the dial. This constrains the design of the train and the 4th wheel must revolve once in 60 seconds. So it is very likely that all three watches have identical calibres.

As well as these photographs, we have concrete information about one watch. In 1989 David Penney examined watch number 164 and made drawings of it. Unfortunately Penney has not yet published the details of his examination, but in a letter to me, he made the following observations:⁷⁷

First

*"Pivots and bearings in the frame are **not** conical. The brass seatings hold a steel screw with a jewel at the end for adjusting endshake".*

This method is described by Crossman as being *"used until they commenced jewelng in the regular way"*;⁷⁸ presumably the change occurred when they moved to New York. In contrast, Tom McIntyre states that

"The pivots of the train wheels are held and adjusted for end-shake with hardened steel screws. The screws have conical recesses in

⁷⁶ Camus, pages 28-49.

⁷⁷ Penney [2].

⁷⁸ Crossman [1], page 5.

their tips that mate with the conical ends of the wheel pivots".⁷⁹

I presume McIntyre was not able to disassemble the watch and he assumed there were conical pivots on the basis of statements by other writers. A consequence of the screws holding end-stones is that the pivot holes must be in the plate and must be quite thin.

Second,

"Lantern pinions are crudely made and obviously took great effort to produce. As finished steel pinions were readily available, I believe that they were used so that the depthing of the train was not critical, rather than just an ambition to 'make it all themselves'."

Third,

"The frame and train are crudely made and finished ... There are many signs of hand finishing".

Fourth,

*"From this and other features in the watch, such as a [balance] cock designed so that it could be adjusted slightly (a single screw in the circular foot and single steady pin) and endshake adjustable pivot settings, it is clear to me that interchangeability was **not** part of the Pitkin's plan and that the lack of ability to manufacture to close tolerances forced them to adopt a system that could tolerate this - effort that would no doubt have been better put to improving manufacture."*

In addition, Penney notes that this watch has a Massey lever type 3 escapement.

Thus this watch confirms the previous deductions. As it is reasonable to assume that the Pitkins skills and techniques improved over time, we can conclude that all watches up to number 163 can be no better made than watch 164. That is, all were hand made.

Before moving on, I should comment on the Pitkins' New York watches. According to Wingate, in 1841

*"only a few weeks after the young company had been set up in New York, the first New York model Pitkin rolled off the assembly line."*⁸⁰

Wingate also states that

"confusion still exists over why the Pitkins built two distinctly different models of watches ... I personally believe that the changes were made because of improvements",

and that

"after ... examining the New York model, and observing the accurate finishing of the pinions, I find it hard to believe that, with the

machinery they had, they could have finished it so well".⁸¹

Anyway, it would seem from serial numbers that the Pitkins could have sold up to another 200 watches in the 4 years before Henry took his own life. However, Crossman suggests that watch number 378 *"is undoubtedly one of the first produced after their removal"*⁸² and it may be that only about 50 watches were made with numbers between 350 and 400; so the total production of the Pitkins could have been less than 250.

Whatever opinion we hold, there is a significant difference in the design and manufacture of the New York watches compared with the Hartford watches: three-quarter plate compared with full-plate with sunk balance; steel pinions compared with lantern pinions; and standard pivots compared with conical pivots and pivot screws. Consequently little if any of the Hartford machinery, if it was more sophisticated than turns, mandrels and other simple hand tools, could have been used and the Pitkins *must* have built entirely new machinery for the new watch. Also, there must have been a substantial improvement in the Pitkins' skills or they employed someone better trained than themselves. Even if we discount Wingate's *"a few weeks"*, this is simply not credible. Compare the time-frame and the number of people, with how long it took Dennison, with far greater resources, to get his watch manufacturing up and running. Sad to say, a jury, taking into consideration that the English did make some going-barrel watches, would find it hard not to decide that the Pitkins used imported English movements. Hoke supports this view, but unfortunately does not say why.⁸³

For Eight Days Shalt Thou Labour

The next important contribution to American watchmaking was that of Aaron Dennison.

In 1830, some 8 years before the Pitkins started making watches, Aaron Dennison was apprenticed to a clockmaker. From that moment to the beginning of 1857 he was a motivating force behind the development of an American watch, and he has frequently been called the "Father of American Watchmaking". I don't know where this epithet came from, but the earliest use, that I know of, is by Favre-Perret in 1876.⁸⁴

We know precisely when Dennison ceased to be a major force. On February 28 1857 the collapse of his dream began, and on May 9 Royal Robbins bought the remains of the Boston Watch Company.⁸⁵

Although he was still needed, he lost control of the company. He lasted until 1861 when he was dismissed.

79 NAWCC [1], page 12.

80 Wingate, page 385.

81 Wingate, pages 388-389.

82 Crossman [1], page 7.

83 Hoke [1], page 309 note 15.

84 Favre-Perret, page 172.

85 Price, pages 8-9.

So it is during the 26 years from 1830 to 1856 that Dennison must have made his mark, and he must have done something significantly different from what went before. Fortunately there is enough information on this period for us to get a fairly good picture of events.

In somewhat flowery language, Abbott says that it was during his apprenticeship that Dennison was supposed to have

"first thought of making watches by machinery. With absolutely no practical knowledge of machines excepting that gained at his master's bench with a watchmaker's lathe [turns or mandrel], he saw possibilities which only the brain of a mechanical genius could conceive".⁸⁶

This is wrong, and Price notes correctly that at this time

"Dennison first envisioned making cheap brass clocks incorporating his ideas for interchangeable parts",⁸⁷

a statement Dennison himself makes in his biographical sketch.⁸⁸ And he was clearly not thinking of mass-production in a factory, but the manufacture of a small number of uniform clocks simultaneously so that the work could be done more efficiently. There is nothing particularly original in this, as mass-production of clocks was well under way.

Not only did he think about it, according to Moore, repeated by Hauptman, it was while an apprentice that

"... he invented an automatic cutter for making the wheels which ... form the gear train of a watch".⁸⁹

Again this is wrong and Cutmore, citing Dennison, says correctly that

"he made a model of an automatic machine for cutting clock wheels during this period".⁹⁰

However, Marsh makes it clear that automatic machinery is very complex and was not developed until the 1860s or later.⁹¹ This, with the lack of concrete evidence, indicates that Dennison may have built a modified wheel cutting engine that could cut a stack of wheels, but it would have been in no sense automatic and was probably similar to the machine patented by Japy in 1799, shown in Figure 6.⁹² This uses a fixed cutter *L* and a stack of wheel blanks *C* mounted on a moving carriage. There is no dividing plate. Instead an endless screw mounted on the handle *L* meshes with the wheel *F* to rotate the wheels.

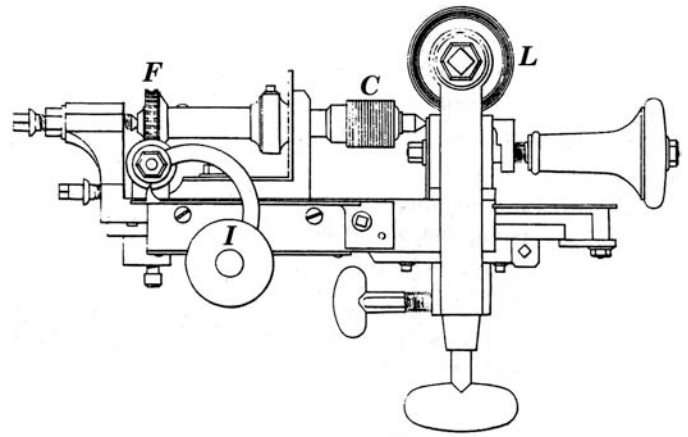


Figure 6 (Reproduced from Japy, page 6)

Dennison's later attempt to use such a machine for watch making failed miserably,⁹³ so despite Dennison writing that *"I constructed an automatic wheel cutting machine which I set up and operated ..."*,⁹⁴ it was not automatic and it is unlikely that it was successful.

Dennison's brother wrote the following:

"He drew the logical conclusion that, if watches were to be improved, only making them by machinery could accomplish it; but this involved making each of the parts on a separate machine and assembling them, which meant that similar parts of any two watches must be interchangeable. So he proved that watches made with interchangeable parts would run, by clamping together six forms of brass and thus cutting out the parts in gangs of six, and immediately turned his mind to the development of watch making machines".⁹⁵

This makes some sense if it refers to cutting clock wheels, or making the plates for cheap brass clocks, but the accuracy needed in watch work could not be obtained. Dennison's brother also wrote:

"In this idea of interchangeable parts Aaron only saw an added advantage to come to the repairer, although the rest of his trade regarded it as an insurmountable difficulty".

As we will see later, an advantage to the repairer required detailed records, because the necessary interchangeability could not be achieved, and these records were not kept before 1857.

Dennison's master during his apprenticeship was James Cary, who was presumably a watch and clock repairer, but it is clear that Dennison only learned a little about watches and the emphasis was on clocks. Dennison makes this point in his biographical sketch, when he writes

"Mr Cary, having offered me a partnership interest in his business after I had been to

86 Abbott [1], page 33.

87 Price, page 1.

88 Dennison [1], page 1.

89 Moore, page 5; Hauptman [2], page 923.

90 Cutmore, page 26.

91 Marsh [3].

92 Japy, pages 5-6.

93 Crossman [1], page 19.

94 Dennison [1], page 1.

95 Dennison [4].

*Boston to get some experience in watch repairing under some superior workman. Upon this offer I abandoned the clock scheme and went to Boston”.*⁹⁶

So he went to Boston, where

*“he offered his services free gratis to Messrs, Currier & Trott”*⁹⁷

for three months. After which, in 1838

*“he went to New York City and ... he was able to gain from Swiss and English workmen ... a large amount of information about the various methods of doing fine work”.*⁹⁸

Dennison is rather dismissive of his stay in New York, saying

*“aside from case making and mainspring making and the usual jobbing of replacing the broken parts of movements, there was little done”.*⁹⁹

This is rather peculiar. I very much doubt if mainsprings were made, unless he means cutting to length and hooking in to the barrel; and case making was a trade entirely separate from watch making, about which he could only have learned the basic principles in the time he was there.

So much of the ten years from 1830 to 1840 was spent educating himself in the traditional craft of watchmaking. Later events (in particular his 8-day watch design) indicate that his education was less than perfect, and we can be confident that he did not think of watch factories and automatic machines in the early 1830s.

During this time, Dennison devised

*“a gauge upon which all the different parts of a watch could be accurately measured ... which I was in the habit of supplying my customers”.*¹⁰⁰

Dennison went on to write:

*“It will be observed that this system of accurate gauging is one of the principle points of interest in the establishment of watch manufacture in the United States, but for this purpose I concluded that it would be best to adopt for a basis the French measure owing to its having a scientific basis, dividing the millimetre into 100ths”.*¹⁰¹

And his gauge was later described as

*“an article indispensable to every watch-maker, who, may by its use, size wire or plate to all the sizes indicated by any Stubb’s gauge, also the diameter of wheels and pinions, most perfectly”.*¹⁰²

However, a detailed examination of Dennison’s “combined” and mainspring gauges shows that they are based on the English imperial inch and they are definitely not metric.¹⁰³ Which did not stop people pretending they were metric and

*“in regard to mainspring thickness, the Dennison gauges equal approximately 13/16ths of a tenth of a millimeter or about 0.008mm”.*¹⁰⁴

Anyway, measurements made with such a gauge can only be approximate and it would be far too inaccurate for interchangeable parts other than those, like mainsprings, which have reasonably large tolerances.

There is no evidence that Dennison ever used the metric system, unless it was after he left Waltham in 1861; the change in gauging under Robbins was driven by Ambrose Webster.

Most sources date Dennison’s interest in watch manufacture to the 1840s and Abbott quotes Dennison himself saying that it was around 1839 that

*“... as far as I can recollect what my plans then were as to system and methods to be employed, they were identical with those in existence at the principal watch factories at the present time.”*¹⁰⁵

This, as I will show later, is not true. I have no quibble with him conceiving the idea, but what he envisioned and did has little in common with the watch factory of 1860. But certainly by 1845, as Crossman states,

*“his mind was still intent on the plan of establishing watchmaking on the well known system of interchangeability as practiced at the Springfield Armory and among the Connecticut clockmakers ... He visited the [Springfield] armory and did a great deal of planning ...”*¹⁰⁶

and according to Abbott he

*“predicted, in the year 1846, that within 20 years the manufacture of watches would be reduced to as much system and perfection and with the same expedition that fire-arms were then made in the Springfield armory.”*¹⁰⁷

Just what Dennison learned from his visits to the armory and clockmakers is a matter for conjecture. Fitch, comparing the early attempts by Whitney with the practice in 1880, makes a very important point:

“If gun parts were then called uniform, it must be recollected that the present generation stands upon a plane of mechanical intelligence so much higher ... that the very

96 Dennison [1], page 1.

97 Crossman [1], page 11.

98 Crossman [1], page 11.

99 Dennison [1], page 2.

100 Dennison [1], page 2.

101 Dennison [1], page 3.

102 Sherwood, page 66.

103 Watkins [3], pages 27-34.

104 WMDAA, page 9.

105 Abbott [2], page 11, Abbott [1], page 35, quoting Waldo, page 187, quoting Dennison [5], page 1.

106 Crossman [1], page 12.

107 Abbott [2], page 35.

*language of expression is changed. Uniformity in gun-work was then, as now, a comparative term; but then it meant within a thirty-second of an inch or more, where now it means within half a thousandth of an inch. Then interchangeability may have signified a great deal of filing and fitting, and an uneven joint when fitted, where now it signifies slipping in a piece, turning a screw-driver, and having a close, even fit".*¹⁰⁸

Certainly by 1845 things had improved considerably from the early 1800s, but progress took time and Dennison would have seen a manufacture somewhere between these two extremes.

Most importantly, just as the Pitkins discovered ten years earlier, both at the armory and at the Connecticut clockmakers he would have seen machines and manufacturing methods of little use in watchmaking. The difference in scale and the different requirements for uniformity mean that only the most general principles would be transferable; the principles of a factory using some sort of machinery to produce uniform parts, with considerable hand finishing to satisfy the requirements of gauging.

So when he persuaded Edward Howard to help him set up a watch factory, Dennison had a reasonably good grounding in the traditional "art and mystery" of watchmaking, no training as a machinist, and some vague idea that it could be done by machinery. Consequently it is hardly surprising that he failed.

There is no question that he failed. As Crossman puts it, in the fall of 1849

*"Mr Dennison commenced to experiment and to build machinery after his own ideas." [He built an upright lathe] "to form the watch plates, with all their cuts and cavities at one moment" [and] "a set of dies and punches whereby all the holes could be punched out at one time."*¹⁰⁹

Apparently these were the only tools built then, but according to Hauptman, by the summer of 1850

*"several other pieces of equipment were partially completed and a hand made model of the watch they hoped to produce by machinery was finished."*¹¹⁰

So they started making watches, only to discover that their preparations were hopelessly inadequate. The plate presses did not produce plates with holes "alike and in the same place every time". And a wheel cutting engine designed to cut several wheels at once, was so bad that "no two wheels ever came out of the machine the same size".¹¹¹ So, according to Hauptman, they got an ordinary English wheel-cutting engine to

use until they could perfect their own.¹¹² It is probable the plate lathe was no better. Unfortunately there is no information about other machinery, but we can be pretty sure the rest consisted of conventional lathes and mandrels.

Crossman quotes Howard saying

*"Mr Dennison was a very fine watchmaker, but as a machinist and builder of watch machinery he was certainly not a success".*¹¹³

Abbott and Moore simply say

*"Mr Dennison's machinery was not a success", [and] "the company had no choice but to redesign Dennison's original equipment and build new machines".*¹¹⁴

So

*"one of Mr Howard's men was detailed to help Mr Dennison, and after numerous attempts, they finally succeeded in getting together a few tools and machines of anything but perfect construction".*¹¹⁵

In fact Dennison admitted this in a letter to Crossman:

*"There is one other item which I should have preferred not to have seen in print (though true enough) as it did not seem called for and that is my friend Howard's opinion of my abilities as a machinist or tool maker. I never made any claim in that direction and being put in that way it looks as though I had".*¹¹⁶

This summary of events overlooks two major points.

First, neither of the two original machines described by Crossman make sense. The most obvious problem is that it is not possible to have "a set of dies and punches whereby all the holes could be punched out at one time." Perhaps this might be done with brass clocks, having thin plates and relatively large holes, but surely Dennison was sufficiently aware of the problems to realise that it was out of the question for watch plates. A punch is a punch and a drill is a drill, and the two are utterly different. So we must presume Crossman is describing two types of "dies"; one type to press out plates, and a second type to act as a master-plate guide for drilling holes.

The upright lathe is equally confusing. At first I thought Crossman meant that the lathe arbor was mounted vertically, but this is both pointless and inconvenient. A much better interpretation is that the lathe was an *uprighting lathe* which enabled cuts in one plate to be made directly over a corresponding point in another plate. But this is simply a mandrel, or a lathe with a face plate, which allows a piece to be mounted eccentrically and positioned by a steel point

108 Fitch, page 618.

109 Crossman [1], page 14, quoting Howard.

110 Hauptman [2], page 924.

111 Hauptman [2], page 927; Crossman [1], page 19.

112 Hauptman [2], page 927.

113 Crossman [1], page 14.

114 Abbott [1], page 17; Moore, page 16.

115 Abbott [1], page 17.

116 Dennison [3].

passed through the mandrel's arbor. Indeed, the term *upright tool* was used for the mandrel in the eighteenth century.¹¹⁷ Crossman's description does suggest something more sophisticated and it reads as though Dennison made a tool equivalent to Ingold's plate lathe, which is described by Carrington and Penney.¹¹⁸ This plate lathe was not automatic and "the degree of 'interchangeability' of the plates therefore depended upon the accuracy with which the operator could reproduce the pre-arranged series of settings".¹¹⁹ But Dennison denied having any contact with Ingold¹²⁰ and the actual form of his upright lathe remains a mystery. However, in 1877 Henry F. Piaget wrote

*"For it is certainly a fact that the machinery of Ingold (who is still living in Switzerland), was first used in Boston in the year 1852 where the first American watches were made".*¹²¹

Unfortunately Piaget did not add any details. Being a Swiss in New York, it is possible that he met Ingold and had good reason for this statement. But his avowed Swiss-ness, together with the almost irrational attacks on Americans in this book, must cast doubt on what he has written, and I am not sure that we should place too much weight on his claim that Ingold's machinery formed the basis for the Roxbury factory. Equally, how much weight can we place on Dennison's denial? After all, to admit to the use of Ingold's machinery would have seriously impaired his reputation.

But one point supports the view that Dennison's upright lathe *was* Ingold's plate lathe or based on it. And that is that Dennison was, on his own admission, not capable of designing machines. Such a lathe requires considerable skill and experience which he did not have.

The second point that I have overlooked is it is clear that, as with the Pitkins, the machinery we know about performs just a tiny fraction of the tasks involved in making a watch. Once again, the only parts of a watch made by machinery are the plates and wheels, and the huge number of other processes and parts are simply not mentioned. And once again, we should assume that Crossman's silence on other machinery means that there was no other special machinery; to imagine Crossman failing to even mention other machines is not credible. Indeed, Torrens suggests that at Roxbury

*"there was very little in the way of tools and machines at all".*¹²²

In addition, such dies and guides must be designed to suit a *particular* calibre, in this case Dennison's first 8-day watch. And, just as most of the Pitkins' tools would have been useless for making their New York watches, most of Dennison's tools would be useless for making the 30-hour watch that followed.

There is considerable confusion regarding the first watch, because there were *two*, quite different eight-day watches, and many authors do not distinguish between them. Crossman is one of the few authors who describe these watches correctly.

The *first*, which was the *only* watch that we are certain was designed by Dennison, was an eight-day watch with a single mainspring barrel. To cite Crossman, Dennison

*"designed it to run for eight days, but it proved a failure from the start... the **barrel** was not large enough to take a spring that would run it through the whole period of seven days on correct time, as it would loose three or four hours towards the latter part of the week."* (my emphasis)¹²³

Because punches and dies must be made for a particular calibre, this watch must have been designed in 1850 or earlier.

But the watch Dennison designed was no more successful than his machines. Crossman says

*"Mr Dennison made his model to a large extent after the Perry English movement".*¹²⁴

However Priestley suggests that

*"in his autobiography, Aaron writes that he based the general layout of the first Roxbury watches on a Joseph Johnson fusee".*¹²⁵

But

*"it would be impractical to make fusee chains in quantity in the U.S., importing one for each watch would be severely restrictive and expensive",*¹²⁶

so the fusee was probably dropped for practical reasons rather than because of a considered design change. Either way, the English watches would have been standard 30-hour movements and why Dennison attempted to convert the model to run for 8 days is a mystery, and it proved to be a total failure because of isochronal errors.

All that we know about the first 8-day watch comes from Crossman: it was approximately 18-size, based on an English full plate 30-hour movement; it had a single mainspring barrel; and it had an additional wheel and pinion to provide the extra 8:1 reduction necessary for eight days running. At least one model of this watch must have been made and tested, but there are no surviving examples. However, it is possible to

117 Martin, pages 576-577.

118 Carrington, pages 700-706; Penney [1], pages 12-15

119 Torrens, page 178.

120 Penney [1], page 18; Waldo, page 188; Torrens, page 178..

121 Piaget, page 51.

122 Torrens, page 183.

123 Crossman [1], page 17.

124 Crossman [1], page 16.

125 Priestley [1], page 98, possibly citing Torrens, page 183.

126 Priestley [1], page 99.

deduce some important points about its design from this meagre information.

First, the size of the barrel is restricted to about half the diameter of the movement. The barrel in this 8-day watch must be slightly smaller, because it must clear the center wheel pinion instead of meshing with it. It is possible to have a larger barrel, and Roskopf did so by utilising a novel train which did not have a center wheel.¹²⁷ Also, the barrel can be made larger if the center wheel is moved so that it is no longer in the center of the movement, requiring an off-set dial or special motion-work. But Dennison's design was based on a traditional calibre, and neither of these arrangements is possible. As he stated,

*"a solid English full-plate watch was the thing most in favour by dealers in the United States ... and the mass of wearers desired a good large size ... I concluded that, in order to succeed, an establishment should be confined in the first instance to the production of such a class of watch exclusively".*¹²⁸

So a larger barrel could not be achieved by using an unusual calibre.

Second, in order for the barrel to drive the train for 8 days, it is necessary either to have a mainspring about 6 times longer or to insert an extra wheel and pinion between the barrel and the center wheel. Because of the size of the barrel, we can be confident that this extra mobile would have to produce an 8:1 reduction. Although such a reduction enables the use of a short mainspring, with about 7 or 8 turns, it requires a much stronger spring in order to transmit enough power to the escapement. As Berner points out, the strength of a spring is primarily dependent on its thickness, the height having much less influence.¹²⁹ Consequently, the spring for such an 8-day watch must be much thicker than one for a 30-hour watch.

Third, the torque produced by a spring varies with its winding state. The line *H* in Figure 7, adapted from Berner,¹³⁰ shows the variation in torque of a normal 30-hour mainspring, and the line *N* illustrates the way in which the torque in a much stronger spring will vary.

We can draw a number of conclusions from these points. First the barrel has to be appreciably larger than that for a 30-hour watch to allow for the increased thickness of the mainspring. Second, in order that the barrel does not extend too far outside the plates, the size of the watch must be increased; despite Crossman's statement, it is very unlikely that it could have been 18 size. Third, a lack of isochronism will be a much greater problem due to the much larger variation in mainspring torque; that is, there would be

a much greater variation in the rate of the watch caused by the balance taking different times with different arcs of vibration.

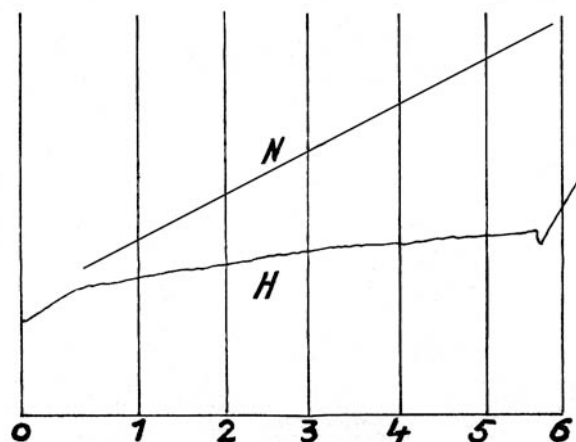


Figure 7 (Reproduced from Berner, page 12)

Equally important is that Crossman's discussion of this watch, which has been rather carelessly repeated by some later writers, is wrong in one respect. He writes that Stratton (who did not join the company until 1852) utilised the stock of parts:

*"the changes were to cut the barrel bridge in the center [and use the two halves for the barrel bridges of two 30-hour movements] ... and, of course, throw aside the extra set off wheel and pinion, which had been used to make it run eight days ... the third wheel, which previous to this had run under the center wheel after the English style, was now raised to run over the center wheel ...".*¹³¹

From this it is clear that at least part of the train had to be discarded as re-arranging the third wheel could only be done by making a new arbor and pinion. Also, it is simply not possible to cut the barrel bridge in half and create two bridges for 30-hour watches. Irrespective of whether the 8-day watch was 18 size or larger, the barrel bridge would not cover much more of the top plate than one in a 30-hour watch. At best it could be made a little narrower and turned a little smaller to fit the new top plate.

(I must insist that we do not throw the baby out with the bath-water. Crossman is one of the few, I think the only author who provides useful accurate detail that can be relied upon, and his book is vastly superior to the other early accounts of American watchmaking. The occasional error should be accepted.)

Later, perhaps towards the end of 1852, the brothers Oliver and David Marsh designed a *second* eight-day watch with two barrels. Marsh incorrectly states:

"Lacking the judgment, which years of experience would have developed, the two

127 Buffat.

128 Dennison [1], page 3.

129 Berner, page 17.

130 Berner, page 12.

131 Crossman [1], page 17.

young men [Dennison and Howard] decided to create a movement which would run eight days with one winding. Such a model was made, indeed several reproductions were made, but a brief trial sufficed to demonstrate the fact that owing to the varying power of the mainsprings (**of which two were provided**) it was found impossible to secure a constant rate of motion throughout the long interval between windings" (my emphasis).¹³²

So Marsh, like others, has merged the two, quite different eight-day watches into one and much confusion has resulted. Although later, in 1909, Marsh almost corrected this error by writing

*"it was an early, if not the original, proposal to manufacture a watch designed and constructed to run a week at a winding. A **couple of models** of this kind were made, but its construction was wisely abandoned as being unsuitable for pocket use, and a full plate model of 18 size one day movement was adopted"* (my emphasis).¹³³

The second 8-day watch was made near the end of 1852. Crossman is vague in that he does not state who designed this watch, but

"they were completed before any of the regular watches were ready for market".¹³⁴

Hauptman states

"Dennison still would not admit defeat regarding the ability to produce an eight-day watch. While he and most of the staff were fabricating machinery required to manufacture the thirty-hour movements, he induced Howard to agree to let O.B. Marsh and his brother D.S. Marsh ... make a model of an eight-day movement that was entirely different than the first ... if they would do the work in over time".¹³⁵

Also, Price writes that the Marsh brothers

"were assigned to model a new watch with two large mainspring barrels".¹³⁶

Abbott is more precise:

*"While Dennison was a pretty fair watch repairer, he did not consider that he was equal to the task of making a model for the proposed watch, and this work was intrusted to two brothers, Oliver and David Marsh."*¹³⁷

This movement was about 22 size and had two mainspring barrels. Price illustrates two surviving examples with a useful photographs.¹³⁸

The first feature to note is that, when viewed from the back of the watch, the positions of the barrel clicks show that both barrel arbors rotate anti-clockwise during winding and so the barrels rotate *anti-clockwise* during running. Thus Crossman is correct when he writes there was *"an extra set off wheel and pinion of course"*¹³⁹. The mobile driven by the barrel must rotate clockwise when viewed from the back and so anti-clockwise when viewed from the dial side, which means it cannot be the center-wheel pinion. So each barrel must contain a relatively weak mainspring, but the total torque of the two mainsprings is sufficient to drive the train. Consequently, the torque produced will be similar to the line N in Figure 8, and lack of isochronism should be no more serious than that in a 30-hour watch.

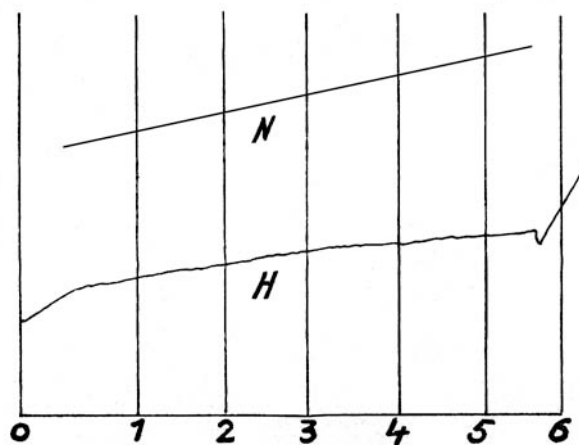


Figure 8

The second point is that Crossman's description of adapting parts to suit a 30-hour watch make sense if he is referring to this two-barrel watch. From Price's illustrations it is clear that there is a single barrel bridge for both barrels, which runs under the balance cock foot. This bridge could be cut in half and trimmed to make two single-barrel bridges. However, its shape is nothing like the shape of the bridges used in early 30-hour watches, and so even this possibility seems unlikely. Even if the bridges were punched out as plain blanks and the cut-out for the click and spring done later, it is unlikely they would be usable.

Although this second 8-day watch was apparently successful, in that it kept time reasonably well, it was a failure in commercial terms and very few were made. (This was probably due to the cost of manufacture being too high. It is likely that they cost more than \$60, which is more than \$1,478 in today's money.¹⁴⁰)

Price believes 19 were made, two prototypes and 17 production watches.¹⁴¹ But if Crossman is right, many more were started and then cannibalised for the 30-hour watch; Hauptman says 100 were started,¹⁴² but

¹³² Marsh [1], page 6.

¹³³ Marsh [4], page 9.

¹³⁴ Crossman [1], page 18.

¹³⁵ Hauptman [2], page 929, citing Crossman [1], page 18.

¹³⁶ Price, page 2.

¹³⁷ Abbott [1], page 48.

¹³⁸ Price, page 2.

¹³⁹ Crossman [1], page 18.

¹⁴⁰ Inflation.

¹⁴¹ Price, page 2.

¹⁴² Hauptman [2], page 930.

we can assume that Howard refused to transfer workers from the 30-hour watch to complete them.

Anyway, even if it had worked they couldn't sell the watches! Dennison had gone to England in 1850

*"for information, and particularly to learn the art of frosting and gilding watch movements. He reported on his return that he had succeeded, and no further attention was given the matter till the time came for doing that work. When he (Dennison) attempted to do the gilding he found himself unable. He and some others worked according to the knowledge he had, and all the reasoning that could be brought to bear on the subject for a long time, without success".*¹⁴³

So there was a small pile of movements "in the grey" and no way of finishing them. (This may be an exaggeration; Hauptman states that Dennison could gild plates, but they "looked very poor".¹⁴⁴ Either way, the watches were not saleable.)

At this point it would not be surprising if the infant American watch industry had died prematurely. All Dennison had achieved in two years was to spend a lot of money building some completely inadequate machines and designing a watch that was worthless. But Dennison and Howard were rescued by two people with far greater watch and machinery design skills.

The Road To Oblivion

In 1852 Charles Moseley arrived at Roxbury. Although he knew nothing about watch making, he *did* know about machines, having worked for many years on machinery for wool and rifles.¹⁴⁵ If nothing else, he has a permanent place in history for replacing the dead-center and wax-chuck lathes which had been used up to then by the hollow draw-tube, split-chuck lathe that has dominated watchmaking ever since. From the time of his arrival there was some chance that the machinery might work.

And also in 1852, N.P. Stratton joined the workforce. As Hauptman puts it,

*"Stratton immediately found himself at loggerheads with Dennison [over the first 8-day watch design, and] with the aid of Howard he convinced him ... and they decided to change it to a 30-hour movement".*¹⁴⁶

And then, in the fall of 1852 Stratton went to England to learn what Dennison had failed to, how to gild, and on his return the company could at last produce something that could be put on the market.

Abbott indicates Stratton and Dennison had worked together before this time, and it is worth quoting him:

"In 1836, [Stratton age 16] was indentured apprentice to Henry and J.F. Pitkin ... In the

*fall [of 1837] Henry Pitkin conceived the idea of manufacturing watches, and Mr Stratton commenced work on tools and machinery for this enterprise, continuing work during the remainder of his apprenticeship ... After the discontinuation of the Pitkin factory, Mr Stratton worked at various mechanical pursuits until 1849, when he entered the employ of A.L. Dennison as a watch repairer. In this position he stayed but a short time, as Mr Dennison had arranged with Howard and Davis to engage in the making of watches by machinery. It has been suggested by those who were very conversant with the early history of watchmaking in this country that it is very possible that Mr Dennison got the idea of interchangeable watch parts from N.P. Stratton".*¹⁴⁷

According to Crossman, after Stratton left the Pitkins he worked at the Springfield armory and as a watch repairer before joining Dennison at Roxbury.¹⁴⁸

There is one problem with this story: Why didn't Dennison invite Stratton to join him at Roxbury? Or, if he did, why didn't Stratton accept? It seems quite possible that there was some animosity between them before the events of 1852. Whatever the reason, Stratton arrived in the nick of time to help Moseley rescue the critically ill company.

From the beginning of 1853 to the end of 1856 the Boston Watch Company made about 5,000 movements. According to Price, after the bankruptcy

*"Howard returned to the Roxbury plant along with some 15 workmen [and] completed about 500 watches".*¹⁴⁹

So a figure of 4,500 finished watches is more realistic. (The number is probably less as there is good evidence that some movements were completed at Waltham after Robbins took over.)

According to Crossman, there were 100 employees producing 6 watches per day (16.6 man-days per watch),¹⁵⁰ and Abbott says that in 1854

*"the company was making about 5 watches per day, and employed about 90 hands" (18 man-days per watch).*¹⁵¹

Webster, quoted by Niebling, also says

*"The daily output at the factory at that time [1856-57] was five watches per day".*¹⁵²

Although a bit vague, these figures suggest a rate of about 17 or 18 man-days per watch throughout the four years 1854-57, which is consistent with Marsh's figure of 18 man-days per watch.¹⁵³ Of course, the

143 Howard.

144 Hauptman [2], page 930.

145 Abbott [1], page 82.

146 Hauptman [2], page 926.

147 Abbott [1], page 51.

148 Crossman [1], page 198.

149 Price, page 9; Geller [2], page 17.

150 Crossman [1], page 24.

151 Abbott [1], page 19.

152 Niebling, page 634.

153 Marsh [1], page 11.

workforce would not have been constant and according to an article in the Waltham Sentinal, it was about 75 in March 1856,¹⁵⁴ but these figures fit quite well with what we would expect from Moore's analysis which I will discuss later.

However, at this rate the company could have made 5,000 watches in about 2.8 years instead of the approximately 4 years that it actually took. Looking at it in reverse, 5000 watches made in four years by 90 people is a rate of 22 man-days per watch; I am assuming a 306 day working year of 51 six-day weeks. Compared to the Pitkins, this is a marginal improvement. Not only that, consider how long it would take competent 18th century watchmakers like Berthoud and Auch to make a watch by hand.¹⁵⁵ Excluding the fusee and chain, it is hard to imagine that the process would take any longer, and the Boston Watch Company had invested large amounts of money in tools and a building simply to keep up with the methods that Dennison and Howard were trying to replace with something supposedly much more efficient.

One figure appears to contradict this evidence. In March 1856, about 13 months before the company ceased production:

*"Messrs. Dennison, Howard and Davis, have been five or six years in establishing themselves in their business ... and in that brief time have succeeded in perfecting machinery and educating workmen to such a degree as to make daily **ten or a dozen** elegant and excellent watches ... They employ about **seventy-five** hands ..."*¹⁵⁶ (my emphasis).

This suggests the company was making watches at a rate of 6.25 to 7.5 man-days per watch, and so there must have been a significant change in methods, tools and machinery to reduce the rate by 11 man-days.

However, in Appendix C I show that such a rate of *manufacture* is impossible and that the company probably did no better than about 16 man-days per watch.

This does not mean the above quote is wrong. It means that watches were being *finished at that rate on those days*. The distinction is very important. Production was, and never is, uniform. So, even though it took 16 days to make a watch, there would be times when many (or few) watches were being *finished*. Which is why Crossman could note that

*"The company then had about one hundred employees ... The company were struggling to make **ten** watches a day, but it was more frequently that **six** only were produced, and very often at the end of the month it was*

*found that not more than one hundred [less than **four** per day] had actually been completed and put on the market"* (my emphasis).¹⁵⁷

That is, rates of 10, 16.7 and 25 man-days per watch. This very large variation is primarily due to variations in the numbers of watches available for finishing.

It is important to note the type of movement manufactured at that time. From Price's data it is clear that all had plain balances with flat balance springs.¹⁵⁸ Such a movement cannot be adjusted for temperature and the expected rate variation makes adjusting for positions or isochronism pointless. These watches, and the English equivalents from which they were derived, are a long way from the later railroad watches. So we can be confident that "finishing" simply involved setting up the escapement and bringing the watch to time. It was not until much later that compensation balances were introduced so that adjusting could be meaningful. Ignoring watch number 5000, which was clearly a special prototype movement and not a production watch¹⁵⁹, the earliest movement signed Dennison Howard & Davis with a compensation balance is dated November 1857, which is after the bankruptcy,¹⁶⁰ but other grades were using plain balances well into 1858 or later; with 3 exceptions the Wm. Ellery grade had a plain or uncut balance right through to late 1877. And nowhere is there any mention of overcoil balance springs in Price's data.

The type of movement is important because the most time consuming, most skilled work is setting up the escapement and adjusting it, a process that could take weeks for a high-grade movement. This work, more than any other, dictates the lower limit to the number of man-days to complete a watch.

So, with the exception of the number of jewels, all watches would have taken about the same time to manufacture, and very little, if any, of the discrepancies in Crossman's figures above can be attributed to the type of watch.

What is apparent is that Dennison, just like the Pitkins before him, manufactured watch parts with inadequate machinery that turned out similar *but not interchangeable* parts. Other than plate presses and a few other tools, much of the work was almost certainly based on trying to streamline and systematise the use of hand tools.

Balances were made by Mr Brown, an English balance maker, who would have used turns, files and burnishers.¹⁶¹ And according to Marsh,

157 Crossman [1], page 24.

158 Price, pages 53-67.

159 Geller [2], pages 21-22; Price, page 72.

160 Price, page 74; Waltham [2], page re3-4.

161 Crossman [1], page 21.

154 Waltham [1], page 144.

155 Berthoud.

156 Waltham [1], page 144.

*"the [screw] threads used in early Waltham watches are said to have been obtained from Swiss 'jam plates'."*¹⁶²

Pinions were hand-made from pinion wire:

*"Here we saw the singularly ribbed pinions cut to proper lengths, turned to proper diameters in their various parts, the leaves recut and polished, and the whole pinion pass through successive polishings until the microscope could detect no lack of lustre".*¹⁶³

More important is Crossman's description of setting jewels, which deserves to be quoted in full:

"The bottom plates were cemented up and the settings cut for the jewels by hand. The jewels were generally set flush with the upper side of the [bottom] plate, then the train and escapement were put in, the top plate laid on, having of course, first drilled the holes through the top plates where the jewels were to be set. Mr Lynch would then sight through on the under side of the top plate and in order to arrange the end shake, he had slips of paper for each movement, and, by means of a few hieroglyphics which he used, he would indicate the location for the jewels in the top plate.

*"When the shoulder was above the lower side of the plate, he would raise the top plate a little on one side until he could see the shoulder, and then measure the distance on the pillar. This seems a very primitive method indeed as compared with the automatic jewel setting and end shaking tools of today; but from long experience the jewelers of that period became very expert".*¹⁶⁴

So not only were the lengths of arbors and the diameters of their pivots all different and not interchangeable, but the crudest of methods requiring great skill was used to adjust the once-similar plates into unique but correctly fitting ones.

Some further information which confirms the view that there was little interchangeability, can be found in the tables provided by Price. In them he lists known, existing watches, and includes much additional data about them where possible. Although limited to visible features and plate diameters, there are a large number of variations listed. As far as plate diameters are concerned, the best that Price can say is that *"all measure nearly the same"*.¹⁶⁵ And illustrations of train layouts show clearly that different arrangements were used at different times.

So it seems that that all Stratton and Moseley did was to provide a life-support system which allowed the

ailing Boston Watch Company to live a little longer. But death was probably inevitable, even without a financial crisis; although, in fact, the real problems of the panic of 1857 occurred after the company had collapsed. The methods were inadequate and the time to make a watch was far too long. Indeed, from the very beginning the company was on a down-hill slide into oblivion.

What was desperately needed was drastic, invasive surgery, a change both rapid and profound to enable the hopes of many people to be realised. Without it, the Boston Watch Company was simply a resurrection of the Pitkins, but larger.

When I began my discussion of Dennison I wrote: "From that moment to the beginning of 1857 he was a motivating force behind the development of watchmaking in America." However, this is not correct. If we ignore our desires and simply look at the facts we know, then Dennison ceased to be a motivating force in 1852. From the beginning in 1850 his ambition was to make machines to manufacture his design for an 8-day watch, and after two years of completely unsuccessful struggles, it was clear that he had failed in all respects. We can presume that it was Howard and Curtis, seeing their investments about to vanish, who brought in Moseley and Stratton and forced the infant company to change direction, build new machinery and make a standard, 30-hour watch. It is at this point that Dennison's role changed from creator to manager, and from then on his role was reduced to supervising and running the factory.

There are two events that support this view.

First, why was the second 8-day watch designed and built? The most likely reason is that it was Dennison's swan-song, his final attempt to exert control and send the company in the direction required by his personal ambitions. Indeed, his conflict with Stratton would have been an attempt to stop development of a 30-hour watch and keep resources focused on an 8-day model. So he refused to be reduced to a manager and forced resources to be diverted from the 30-hour watch to another Dennison idea. He could only do this if much of the development was done outside work hours, because there was a limit to what Howard and Curtis could accept. It is likely that he was allowed to do so from lingering respect and because of his pivotal role in the company. But this watch also failed and from then on Dennison ceased to be a watchmaker.

(It should be remembered that Dennison's later attempts at watchmaking also failed. He did not achieve any sort of success until he moved to England and set up in the far simpler activity of case making.)

Second, after Dennison was finally dismissed in 1861 the board of the company explained why this action was taken. An abbreviation of the board's resolution, given in full by Moore, reads:

¹⁶² Marsh [3], page 95.

¹⁶³ Waltham [1], page 144.

¹⁶⁴ Crossman [1], pages 19-20.

¹⁶⁵ Price, page 5.

*“A.L. Dennison, Superintendent of the Mechanical Department, omitted and neglected to perform the various duties incumbent on him, and has discharged his duties in an unsatisfactory and disagreeable manner, and he has offensively intermeddled with other departments”.*¹⁶⁶

It is clear that this condemnation resulted from a conflict that had been going on for some time, most likely since the takeover in 1857.

Dennison had been kept on as a superintendent and he was needed in this role because of his knowledge. But there can be little doubt that his life-long ambition, to be *the* watchmaker who built an industry, would have created tensions and conflicts as the company moved further and further in a different direction.

Aaron Dennison had a vision. Sadly, he lacked insight and skills to turn that dream into reality.

¹⁶⁶ Moore, page 44.

Part 2: Making The Most Of Time

A Roller-Coaster Ride

To repeat the question I posed near the beginning: What are we missing? There is something which sets the American system apart, but it is not the conventional aspects of factories, machinery, mass-production and interchangeability. And it is not found in the work of the Pitkins or Dennison. Both missed it, whatever it is, and someone else discovered it.

We can see that graphically. Moore produced a chart of the number of man-days to make a watch at different times; see Figure 9. In it, Moore has simplified and idealised reality, creating two smooth curves to illustrate the difference between the watchmaking practices in Europe and America. And in doing so he has hidden several important features, two of which I shall mention now.

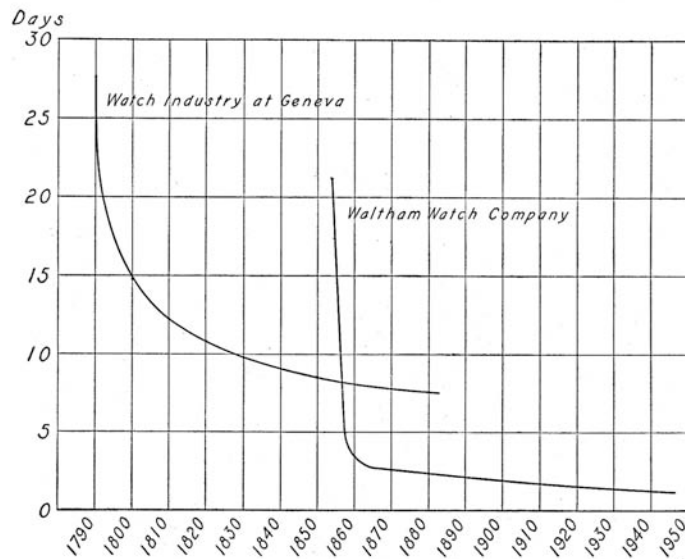


Figure 9 (Reproduced from Moore, page 233)

First, for most of the 17th and 18th centuries the time to make a watch would have dropped slowly, but have been fairly constant. Throughout this period techniques and tools did not change much and Berthoud's and Auch's descriptions of watchmaking would apply to almost any watchmaker at any time.¹⁶⁷ But in the late 1700s Japy and others established factories, and centers like that around Liverpool became major producers. So the rate of watch making began to improve and this continued until the limit of productivity of the tools and labour was approached.

Second, if we consider what happened at Roxbury and Waltham between 1853 and 1857 we have to draw a significantly different picture, as shown in Figure 10. For throughout this period, Dennison and his workmen struggled to make watches and failed to reduce the number of man-days significantly. Then,

¹⁶⁷ Berthoud.

very suddenly, the time to make a watch plummeted from about 18 man-days to 5 or even less. It was not a gradual change, not an improvement grafted by hard work. It was a stunning and dramatic free fall.

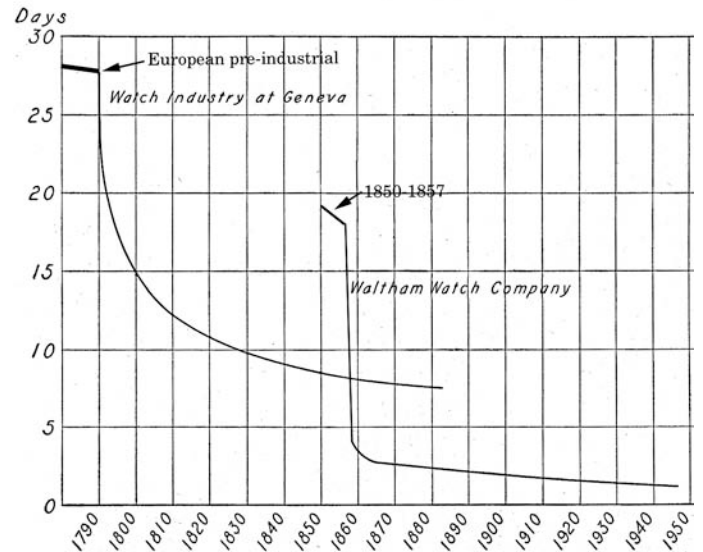


Figure 10

This graph is confirmed by what we know of production. Appendix D analyses production for 1857 and 1858, and it shows that the rate reached about 5 man-days per watch by January 1858 if not earlier. That is, the rate dropped by about 11 man-days (from 16 to 5) in the space of a year.

Moore's graph and Appendix D have another, equally important implication. Not only does it illustrate the labour involved in making a watch, but it also reflects the *cost* of that watch. At a time when the tools and machines were relatively simple, the dominant factor in manufacturing was labour. If average wages were \$1.00 per day then Dennison and Howard had to charge about \$20 for each movement just to cover costs (including materials and the case). But after 1857 this figure dropped to about \$9. And so the affordability and potential for sales of watches altered dramatically. This can be seen from the Waltham sales records;¹⁶⁸ although the sale prices are surprisingly erratic, they reflect this much lower cost.

The precise figures are not important. What does matter is that there was a *rapid, very large change*. And this change simply could *not* have occurred if the factory had continued production using the same methods, tools and staff that had existed before the bankruptcy.

All that we need to know is: what happened?

¹⁶⁸ Hawkins, pages 4-67.

A Spanner In The Works

A spade is a pretty dumb tool; in fact the dumbest tool I can think of. But it is very useful and can be employed to make holes of all sorts of shapes and sizes. Not only that, anyone who isn't badly disabled can use one. A tiny amount of care is desirable, to avoid cutting off toes, but otherwise the operator can be as dumb as the tool. Well nearly. Not long ago a man dug a big, deep hole in the sand on an Australian beach. Unfortunately the sides collapsed and he suffocated. But the problem had nothing to do with the tool, which had performed its function admirably.

Another dumb tool is the watchmaker's turns. What could be simpler than two female centers to hold something and a horse-hair bow to turn the something? The only complication is the addition of a rest to help support a graver while turning. Indeed, it is so dumb you can make one from a few bits of wood and a couple of nails; even making a simple lathe is not much harder.¹⁶⁹ But unlike a spade, the turns are definitely *not* easy to use. It takes considerable skill and a large amount of experience before someone can successfully make watch parts with it. And there are many dumb tools like the turns. For example, a file. Simple, easy to use badly, but quite difficult to use well. Apprenticeships and other watchmaking courses begin with endless filing of taper pins and squares simply because the experience and the development of skill is essential.

A spade might be dumb, but its modern equivalent, a back-hoe or mechanical digger, most certainly is not. Its complex combination of engine, wheels, hydraulic arms and a bucket make it vastly superior to the spade in both speed and power. But otherwise it is the same; just about anything you can do with a back-hoe you can do with a spade, it just takes a bit longer. The big difference is that the operator needs to be trained and experienced or else a disaster is certain to ensue. But a skilled operator can either caress the ground or rip it apart, such is the control and power available.

My fourth and last example of a tool is the digital camera. Turn it on, point it at something and press a button, and the camera does the rest. It focuses on the subject, adjusts the exposure, turning on the flash unit if necessary, and takes a picture. Knowledge of photography and cameras is not needed, there is no skill required, and the dumbest amongst us can take a good photograph almost as surely as a well educated professional.

These four examples of tools illustrate the various ways in which we have created machines to enhance our abilities and our productivity. They show an important relationship between the dumb or complex tool and its dumb or skilled operator. And they explain why every early attempt to mass-produce watches with

interchangeable parts either failed miserably or achieved a minimal success.

Machines and tools are created by people. And what people create is strongly influenced by their past experiences and their perceptions.

In watchmaking, these experiences and perceptions derive from 300 years of a master-apprentice system controlled by guilds. This closed system is exemplified by the London Clockmakers Company, whose goal was to protect the *Art and Mystery* of the craft. The art is the skill and experience, and the mystery is the knowledge and understanding. Both were passed down from master to apprentice, and the apprentices who proved their competency by making a "master piece" became the next generation of masters and continued the secretive, tightly controlled distribution of education.

Apprentices entered their chosen trade when about 14 years old, and after 7 years they became journeymen, able to work but not yet competent to be masters; indeed, large numbers remained journeymen throughout their lives, working for masters or for factories. This organisation meant that the only education watchmakers or any other tradesmen received was dictated by their masters. The type of education and its content was directed to practical watchmaking and practical experience dominated. Very few people in such a system had the opportunity or inclination to study in areas outside those provided by their masters, and consequently the same information and skills were passed down from one generation to the next with little modification. This closed-shop system rewarded watchmakers by providing a stable, fairly safe working situation, but it actively discouraged and prevented change.

The only significant alteration to this educational structure was the result of splitting up the activities of watchmaking into a large number of sub-crafts. But these derivative trades followed the same educational organisation, using the master-apprentice system to propagate knowledge and skills in each sub-craft in the same way, and so produce journeymen, graduate apprentices, specialising in plate making, wheel cutting and 50 or more branches of watchmaking.

A good example of the effects of this system is the "mystery" of wheel cutting. From the beginning until well into the 19th century, wheel teeth and pinion leaves were shaped like thumbs and bay leaves in a tradition handed down from one generation to the next, and despite a translation of Camus' 1750 work on gears by Hawkins, knowledge of epicycloid gearing was almost totally absent.¹⁷⁰

These different trades involved varying degrees of knowledge and skill, but all required on-the-job training and all journeymen had significant, specialist skills.

¹⁶⁹ Whiten, pages 43-44.

¹⁷⁰ Camus.

Not all workmen were competent. In 1804 Crespe had to warn his reader to check the number of teeth on wheels in case there were too few or too many! So even the relatively simple wheel cutting engine was misused.¹⁷¹

Also, the system was abused. As a House of Commons committee noted, apprentices worked in factories in Coventry with 30 or more under the supervision of a single journeyman, and they received minimal, inadequate training. They were basically cheap, unskilled labour producing cheap, badly-made watches. When they had completed their seven year's apprenticeship, they were dismissed because, as journeymen, their wages would be higher. But, because their education was so poor, they could not find jobs elsewhere.¹⁷²

An important effect of this closed system was that it produced blind and irrational opinions to support it. A relevant example from 1860 is a letter by "one who admires good work":

*"I have seen a National watch from America, and confess I could discover nothing very alarming for English watchmakers in any part of it, especially as it was to a great extent merely a rough and tasteless agglomeration of parts manufactured in England, apparently got up for the purpose of turning national vanity to account; and I should be sorry to see Englishmen drawn by any such ruse to abandon the vantage ground time has granted to them, for I am confident that the genius that originated and gradually brought to its present perfection the art of chronometry may be excused from copying every sample of trash that roughly measures time."*¹⁷³

(This is confusing because the Elgin company was not started until 1864. However the sentiments are what concern me.)

Originally *all* the skill lay with the watchmaker. Wheels and pinions were divided by hand and the leaves and teeth filed into shape. By the time of Berthoud and Auch the machines were becoming a little more intelligent. But even then teeth were hand-shaped. And correct depthing was achieved by plugging all the holes in the plates and re-drilling them in the right positions. The point is that although these machines improved productivity they still required highly trained operators, and watchmaking was firmly based in the skill and knowledge of the masters. So, although mass-production and a degree of standardisation was achieved there was one insuperable barrier to progress: *the machines were dumb*. Almost the entire skill of watch making rested with the highly trained journeyman, and so the

original factories recreated the watchmaker's bench *en mass* in factories to gain the benefits of the co-ordinated manufacture of similar parts.

The earliest factory of which we have some details is that set up by Frederic Japy in Beaumont. Fortunately Japy decided to patent his machines and so we have precise descriptions of them.¹⁷⁴ There were ten machines: a circular saw, a plate lathe, a wheel cutting engine, a pillar lathe, two presses to punch out balances and wheels, a drilling guide, a tool to rivet pillars, another to slit screw heads, and a draw bench.

It has been stated by Cutmore, and repeated by Harrold, that Japy manufactured about 40,000 movements per year with 50 workers,¹⁷⁵ but these figures are patently ridiculous. They suggest that Japy made movements at a rate of about 0.45 man-days per movement (this figure is based on workers labouring for 360 days a year with only 5 days off). But Moore, using far more precise data, shows that the rate of production at Waltham was about 3 man-days per movement 1865, 2.5 in 1876 and not going below 2 man-days until after 1889.¹⁷⁶ Even if we accept that Japy produced unfinished movements, ebauches, the figures just do not add up. To suggest he made watches over five times faster than the highly automated, streamlined factory of 1876 is not sensible. However, Cutmore's mythological statement is derived from Landes, who actually wrote:

*"By 1780, we are told, Japy was employing and housing some fifty 'apprentices', **plus numbers of journeymen**, and turning out 43,200 pieces"* (my emphasis).¹⁷⁷

Assuming his ebauches took a credible 15 man-days, then there must have been around 1,700 journeymen. Landes also suggests the figure of over 40,000 is far too high, but even 20,000 at 15 man-days would require some 800 journeymen. We cannot get around the fact that Japy did mass-produce before America, but if a serious comparison is to be made we need much more convincing information.

Of the ten machines patented by Japy we can dismiss four immediately. The circular saw, pillar lathe, drilling guide and draw bench are crude, dumb tools which do not represent a significant advance over older hand tools like hacksaws, turns and free-hand drilling. The drilling guide is a good example. A piece is clamped in the tool and a drill, which is mounted on a runner in a tube and turned by a bow, is used to make a hole perpendicular to the face of the piece. But there is no way to clamp the piece in the right position other than by advancing the drill to touch it while moving the piece with one hand and clamping it with the other hand when it is in position; as Japy notes,

171 Crespe, page 79.

172 House of Commons, pages 43, 73-76, 82, 84.

173 Anon [2] in response to Anon [1].

174 Japy.

175 Cutmore, page 19; Harrold [1], page 28.

176 Moore, page 232.

177 Landes, page 280.

use of the chest as well as two hands is desirable! So the chances of drilling two plates alike is minimal. Of the remainder, the two presses and the wheel cutting engine, which could cut a stack of wheels, are undoubtedly useful advances, but they are in no sense automatic, require skill to use, and speed up processes which represent only a fraction of the tasks in watchmaking. And the remaining three tools are of dubious utility.

The screw head slitting tool enables a number of screw heads to be slit at the one time. The screws are held in a clamp and a hand-operated slitting file moved repeatedly over them. Japy provides no information on how the screws are held in exactly the right position and height, and it is clear that setting up the tool would take some time. Again, it is a dumb machine which enables one task to be done a little faster, but there is no mention of corresponding tools to turn and thread the screws in the first place. Thus only a small part of the task has been improved.

The pillar riveting tool is simply a jig by which the frame and its pillars can be held while a hammer is used to rivet. It would probably be slower than doing the task by hand, but it may be a bit more accurate. However, a much greater problem than riveting is ensuring that the four pillars are turned to exactly the same length; otherwise the top plate would bend when it is fastened. The description of the pillar lathe tells us that it is simply a mill attached to a lathe; whether the result is square or round depends on whether the brass rod for the pillar, mounted in the lathe, is indexed or allowed to rotate freely. This is fine as far as it goes, but nowhere does Japy explain how the two pivots are made on the ends of the rod and consequently how the length of the pillar is controlled. Under these circumstances I would expect that free-hand turning and square filing would be just as easy and probably faster.

Finally, the plate lathe holds and turns a plate while cutters, one mounted in a slide and the other pivoted at the side, are used to shape the edge of the plate and cut a central recess. Plates are located by their pillar holes, the reference system, but presumably cemented to the chuck. By substituting other cutters, the lathe can be used to make other verge watch components, such as the slide and the rack. The most serious defect of this lathe is that there is no way to mount the plate eccentrically and so cut an off-center feature. In addition, play in the lathe components and the reference holes, and wear of the cutters would make producing interchangeable parts virtually impossible. But here we have a machine with a little intelligence built into it, although a skilled operator is still required.

We can now see two very interesting trends. First, the most useful of Japy's tools, presses and a wheel cutting engine, are the same tools that Dennison built

some 50 years later. I am not implying that Dennison copied Japy's ideas, rather that the common thread points to the fact that it is easier to make such tools than machines to do other tasks. Second, the vast majority of watchmaking tasks (plate drilling, screw making, arbor turning, etc.) must still be done using traditional hand methods requiring skilled journeymen; which we can see from the more sensible estimates of Japy's workforce given above.

Consequently, the most that Japy could have done was to organise a manufacture that moved tradesmen from cottages to a single building without significantly reducing the number of man-days to make a watch. But he probably didn't even do that. There is some information on his factory in Allix which suggests that it would be simply impossible to house the nearly one thousand workers in the building. Most likely the majority were still working in their cottages.

The other European attempt to manufacture watches before Dennison was by Pierre Frederic Ingold, a contemporary of the Pitkins. Ingold is championed by many outside the United States, and David Penney takes his life in his own hands by daring to suggest

*"the American System of Watchmaking should perhaps be renamed the Ingold System of Watchmaking."*¹⁷⁸

However, it is clear that this suggestion is not acceptable; if we are to agree with the argument then it must be called the Japy System of Watchmaking as Japy takes precedence.

But what do we know of Ingold's tools and machines? As Penney and Carrington point out,¹⁷⁹ Ingold invented and patented two machines in 1842 and 1843. The first is his fly press for producing wheel blanks. Although an improvement on Japy's presses, it also only assists with a minor part of watchmaking.

Ingold's second machine was his plate lathe. This undoubtedly ingenious hollow mandrel, or face-plate lathe, had an eccentric chuck which enabled any part of a watch plate to be centered according to a pre-set indexing plate and a slide screw. Because the mandrel ran on a hollow tube, cutters could be fed through this hole to form the other side of the plate. Thus sinks and holes could be cut and drilled anywhere on the plate. And because the last step was to separate the plate from its oversize blank, there was no problem clamping it to the headstock. The difference between this and the traditional method lay in the single chucking of the plate instead of a number of separate mountings on a wax brass or face plate. And it is clearly far more versatile than Japy's plate lathe. But although some time may have been saved, just about as much skill and training would be needed by the operator as when he made plates the old way. Further,

¹⁷⁸ Penney [1], page 22.

¹⁷⁹ Carrington.

it is very unlikely that interchangeable plates could be produced. Certainly they would be very similar, but the accuracy of the settings, wear on drills and cutters, and the operator's involvement make it very likely that small differences would occur and some finishing would be needed.

It must not be forgotten that the tolerances for some parts, such as pivot holes, must be measured in hundredths of a millimetre, both in diameter and position. And the more parts a tool has, the more problems there will be with play and other variations. So a little play in the headstock, a little more in the indexing system, yet more in the tool mount, and a slightly worn tool can add up to an appreciable error. It is precisely such problems which made it impossible for Waltham to make interchangeable arbors as late as the 1880s, so what chance did Ingold have?

But again, just as with Japy, the tools and machines we know about perform only a fraction of the tasks in watchmaking. However, unlike Japy, Ingold never got far past the drawing board. As Waldo notes, quoting a watchmaker who visited Ingold's London premises,

*"of the two hundred men said to be employed, the number I saw did not exceed six or eight, these were occupied in making watches without the aid of machinery, employing only the tools generally in use".*¹⁸⁰

So all of them, Japy, Ingold, the Pitkins and Dennison, developed the same types of tools. And in all four cases we are faced with the same questions: How were arbors and pinions made? How were screws and escape wheels made? How was the train assembled with correct depths and end shakes?

But the critical point is that the approach of Japy, Ingold, the Pitkins and Dennison was that of the master watchmaker, which Japy and Ingold were, and the Pitkins and Dennison attempted to be. Mechanisation was seen from that point of view and central to it is the *trained artisan*. And it is safe to say that the majority of tools and methods were designed with the apprentice and journeyman in mind. Thus, all four attempted large-scale watchmaking within the confines of traditional methods enhanced by a few, inadequate machines. Three (and I think Ingold as well if he had ever managed to set up and run a factory for long enough) only managed to reduce the man-days per watch by a small amount. All except Japy failed, and it is probable that he only succeeded because he produced ebauches for a hungry Swiss industry.

At least one useful conclusion can be drawn from this examination. And that is, no-one beat the Americans to it, whatever it is. Nothing done by Japy, Ingold, the Pitkins or Dennison changed watchmaking in the way that events in 1857 must have. Something that was distinctly different caused an abrupt change

in how watches are made, and it is that which makes The American System of Manufacture original and so very important.

What Dennison Missed

Really, Ingold never had a chance. Even if he visited Japy's factory he would have seen machines doing rough work and menial tasks, and people doing the difficult bits using simple tools. But both the Pitkins and Dennison might have seen the light. Both were in easy reach of the clock factories and both visited the Springfield Armory. But they both missed the crucial point of armory and clockmaking practice.

When Dennison went to the Springfield armory he saw a way to manufacture watches by assembling people to work with machines in a controlled factory environment. But other than presses, there is nothing in the manufacturing process for guns that can be applied to watches. And there is nothing in the system of go/no-go testing of components that is relevant to watchmaking.

When Dennison went to the Springfield armory he thought he saw interchangeability. But what he should have seen were reject parts that failed the go/no-go tests, parts that had to be discarded or refinished by hand. He saw a process of *standardisation* of parts that tried to minimise waste but produced waste nonetheless.

From this he could construct a vision of a similar factory peopled by tools and workmen making watches. A factory where similar parts could be created and then massaged into usability, just as had been done in the past. So he and Howard built such a factory and it promptly failed.

It failed, because what Dennison completely missed at the armory was a manufacture that had been *dumbed down*.

One thing that America lacked was enough skilled craftsmen. The number of gunsmiths was simply too small to produce enough rifles to invade the west and equip armies. The number of watchmakers was probably just sufficient to maintain and repair imported watches without worrying about trying to make them.

Contrast this with England and Europe. In both places there was at least 200 years of watchmaking and 200 years of apprenticeship training. In both places there were established industries based on manufacture by skilled artisans. And there were enough of these journeymen, perhaps even a glut.

As Rolt notes, in the early 1850s an English commission reporting on America stated that

"the labouring classes are relatively few in number"

and there was apparently

"a widely held and long-cherished belief that the American System originated solely because of a shortage of labour and the high

¹⁸⁰ Waldo, page 187.

wage rates consequent upon such a shortage".¹⁸¹

Landes expresses this myth in a different way by suggesting

"There was simply no pool of cheap skilled labour [and] the solution lay, of course, in the substitution of machines for labour".¹⁸²

But the machines were too simple to have any significant impact on the number and type of people required.

But one thing America had was an ample supply of *unskilled labour*; there was a wealth of young men and enthusiastic girls with not much education and no skills beyond tending farm animals and crops.

But unfortunately clocks, guns and watches require skilled artisans ...

But they do not! At the core of the American System is the realisation that *complex, sophisticated products can be manufactured by unskilled labour*.

As Fitch notes

*"Whitney ... systematized the work, and by making the parts in lots of large numbers, **employing unskilled labour** for filing them to hardened jigs, and by close personal supervision, succeeded in executing a contract under circumstances which caused the failure of other contractors, who employed skilled craftsmen, filers and gunsmiths to do the work".¹⁸³*

Or, to put it another way, Whitney *dumbed down the workers*.

Although writing about a much later time, Alft and Briska drive home the truth of these statements. An employee at Elgin is quoted:

"I worked for the Elgin company nearly ten years ... and I don't know any more about watch making than millinery".¹⁸⁴

And another employee:

"who had been making canon pinions, didn't know where in a watch the part belonged. It is not necessary that she should ... she could not make them any better or any worse if she did, because she simply tends the machine which does the work".¹⁸⁵

These clearly stress the central feature of post 1857 watchmaking in America, the use of minimally trained, unskilled labour. For the employees, watch making is a mystery, knowledge of which is irrelevant.

A third statement in the same book is also important:

"because 'interchangeable' parts often had to be 'fitted' by finishers, they were among the factory's most skilled employees".¹⁸⁶

Indeed, we could reasonably say that finishers were almost the *only* skilled employees, other than the machine makers. And by 1886

"the great questions ... of determining what kind of labor - whether of boys or girls, or men or women - was most efficient in any department had been settled".¹⁸⁷

and these labourers had

"no specific knowledge of horology".¹⁸⁸

There is a world of difference between filing a part to an accuracy of one thirty-second of an inch and turning a balance staff to within one hundredth of a millimetre. And wooden parts for clocks made with simple jigs also have tolerances which enable fairly crude workmanship to be quickly finished and fitted so that similar parts take on an air of interchangeability. Whether Dennison completely missed the point or found he was unable to transfer it to watchmaking is uncertain. But Abbott strongly supports my contention that Dennison entirely missed this vital factor: About 1843

*"Mr Dennison now began to turn his thoughts to ... the 'Interchangeable System', and here it may be well to state that, among the objects which spurred Mr Dennison on was the need of the masses ... to be supplied with a reliable timekeeper at a price within his means ... and further, he desired to establish a fine mechanical industry in our country which would tend to **raise the standard of skilled labour and give employment to talented mechanics**".¹⁸⁹*

And that is exactly what he tried to do.

As Abbott wrote, in 1850

*"a small factory was built ... and some **English and Swiss watchmakers** were put to work".¹⁹⁰*

So he gathered together some 50 journeymen fresh from overseas, supplied a few primitive machines to supplement the traditional turns, files and burnishers, and tried to mass-produce watches. They *had* to be journeymen simply because the tools and machines were dumb; or even if they had some sort of inbuilt intelligence, they required skilled operators.

Indeed, Dennison was so concerned about the comfort of his journeymen that Crossman notes

"the wings of the buildings were divided into small rooms or stalls ... The reason for this arrangement was that Mr Dennison thought

181 Rolt, page 155.

182 Landes, page 339.

183 Fitch, page 618.

184 Alft, page 32.

185 Alft, page 32.

186 Alft, page 46.

187 Waldo, page 189.

188 Waldo, page 189.

189 Abbott [1], pages 34-35

190 Abbott [1], page 17.

the European workers, who had been accustomed to work in their own homes would be better satisfied to have separate rooms and thus in a measure overcome the jealousy which would exist among them. This plan was, however, found impracticable, and after being in use for about a year the partitions were removed". (my emphasis)¹⁹¹

These descriptions of a factory reliant on traditional, craft-based labour are confirmed by what happened immediately after the bankruptcy in 1857. Robbins, needing to restart the factory as soon as possible, was reliant on Dennison's experience and knowledge to do this. So

"The next day after the sale Mr. Dennison started for England for the purpose of obtaining material which was required and also to arrange for the manufacture of dials there [with the new company name]".¹⁹²

Moore notes that Dennison went to England

"trying to get materials and skilled craftsmen".¹⁹³

In Dennison's own words

"there had existed the necessity ... for the purpose of stocking up a little or to obtain some help or both".¹⁹⁴

To which Moore adds:

"The need for factory hands was also a matter of concern, but the attempt to recruit craftsmen in England was not successful".¹⁹⁵

(It appears that Dennison was happy to be away from Waltham because

"I know [of Robbins] only enough to discover that under all the circumstances, if he was to have much say about the business, the sooner I could make it convenient to leave the better".¹⁹⁶

Which was prophetic of later events.)

Dennison's failure to recruit English workers was because

"we can hardly offer any inducement for an Englishman to emigrate, as workmen in our line, as well as most trades similar such as jewelry manufacture &c &c, are getting quite as good pay and have every reason to be happy here as they could with us".¹⁹⁷

These statements confirm that watchmaking in Waltham had been based on trained journeyman. Consequently, I must disagree with Hauptman when he writes

"Dennison with Howard proved the machine-made watch and the machines that made it to be mechanical successes".¹⁹⁸

Their manufactory was not significantly different to that of Japy and was based on traditional watchmaking augmented by simple machines. What Dennison with Howard actually proved was that *such a factory with its excessive man-days per watch and expensive, skilled labour was a failure*. Don't forget, the bankruptcy not only occurred long before the panic of 1857, but it had probably been foreseen by the middle of 1856 or earlier. The failure was just the inevitable end result of a company that simply could not achieve its aims.

To summarise: The point I am making is that the one essential feature of the American System of Manufacture, which sets it apart from everything that had gone before, is that it uses *unskilled labour*; it *dumbed down* technical, guild-based crafts to the point where the craftsmen were almost redundant. Although mass-production can be seen as a second motivating factor, everything is a *consequence* of dumbing down and not a cause: the development of intelligent machines able to be used by people with just a little on-the-job training; the relocation of machines and people into factories so that these unskilled workers could be supervised; the emphasis on mass-production, because that is the only way the cost of expensive machines and their maintenance could be justified and recouped; and the inevitability that such machines would produce very uniform and, eventually, interchangeable parts.

It could be argued that Japy understood and acted upon this fundamental point. His patent description begins

"The following machines produce the principle parts of a watch, with rapidity and precision, by employing only not very skilful workmen, and can even be operated by children".¹⁹⁹

This view is re-expressed by Allix when he wrote

"[Japy's] outstanding endeavours ... gave work to many people who previously had depended upon the soil for their livings".²⁰⁰

There is no doubt that some of his machines could be used by unskilled people, but these machines perform only a small fraction of the tasks involved in making a watch, and several of them would need considerable skill to use correctly. It is quite clear that Japy was simply speeding up some of the rough work while the majority of the labour had still to be done by journeymen. He was doing exactly the same as Ingold, the Pitkins and Dennison; which is to say, he was not dumbing down watchmaking, but rather he was trying to improve the efficiency of craft-based methods. Like

191 Crossman [1], page 15.

192 Crossman [1], page 38.

193 Moore, page 25.

194 Moore, page 22.

195 Moore, pages 28-29.

196 Moore, page 23

197 Moore, page 29.

198 Hauptman [1], page 691.

199 Japy, page 1.

200 Allix, page 142.

Ingold, he never had a chance, simply because his cultural and educational environment was that of guilds and craftsmanship, and he was unable to see outside this framework. So I have no doubt that everyone before 1857 missed the essential point of unskilled labour, which is not to supplement, but to *eliminate* the craftsman.

Thus the American System of Manufacture is *the manufacture of machines by unskilled labour*.

Three Cheers For Charlie!

Events don't just take place. They occur because some confluence of conditions create a moment which enables dramatic change. The founding of Australia is one such event and it was a consequence of the American War of Independence. England was sinking under the weight of petty criminals who filled to overflowing the rotting hulks on the Thames. But there was a simple solution; ship them off to the Americas, to that vast colony with room to spare for the unwanted convicts. Unfortunately, the free Americans got sick and tired of the "mother country" and kicked England out. What to do? Easy. Send Captain Cook off to locate Terra Australis, claim it and ship the refuse there instead.

It wasn't quite that simple, because there were other factors. One was John Harrison. Through his work the English could see a way not only to accurately map the world but, more importantly, to dominate it; which they did. And so finding Australia killed two birds with one stone; the colonisation of a substitute land to replace America and making a map covered with British flags. I am sure historians will list many other factors, but the point is, if the Americans hadn't gained independence it is unlikely that England would have bothered with Australia.

The same is true of American watchmaking. It took the coming together of a particular set of circumstances at a particularly propitious moment to cause an industry to be created.

The right time was the result of some twenty-six years of attempts and failures by the Pitkins, Dennison and Howard.

The right circumstances were the selling of a nearly *empty factory* to someone who knew *nothing about watchmaking* but who had the will to succeed.

I have argued, and I think demonstrated, that past failures were primarily due to the inability to dumb down watchmaking. No-one had been able to make the leap, to look at the task from a completely different perspective, because all the people involved were *watchmakers*, educated within the narrow confines of the traditional art and mystery. To be able to view watchmaking from a totally different aspect required someone who was not a watchmaker and who was not burdened by preconceptions.

The empty factory was vital. If it had not been empty, the new owner, Royal Robbins, and his

employees would have inherited a working factory and would almost certainly have attempted to continue what Dennison and Howard had started. If that had happened the Waltham company would have failed yet again and almost certainly died.

But Robbins, although he didn't see it that way, was rescued by a shoemaker, Charles Rice. In a letter to C.N. Thorpe, Mr. E. Tracy states:

*"In the fall of 1856 [sic], Dennison, with the knowledge of his firm, began looking around to get someone to put some money into his enterprise of watchmaking, and early in the Fall of 1855, or Spring of 1856, Mr. Charles Rice, a shoemaker of Boston, loaned the money, which Dennison, Howard & Davis secured by **chattel mortgage on all the material, tools, machinery, etc** in the watch factory". (my emphasis)²⁰¹*

Of course, when the business failed, Rice went to the scene and claimed what was rightfully his.

Just what Rice took away is subject to debate. Harrold suggests that it

"is unlikely that many machine tools were taken, for they would have been neither easily portable nor of ready cash value. More likely involved were some small factory tools and semi-completed movements which could be finished using traditional methods".²⁰²

However, four points contradict this view.

First, why would Rice take only *some* of the chattels when it appears he was entitled to the lot? I simply cannot imagine him leaving anything behind that could be removed reasonably easily and which would help compensate him for the loss of his investment. Indeed, any sensible person would take as much as possible to maximise the cash value and the chance of recouping his money. As he too was bidding at the auction, we might assume he left much in the buildings in anticipation of taking them over. But every writer states that he did take much away and it seems unlikely that he would risk losing everything if he failed to win the auction bidding.

Second, virtually all of the watchmaking machinery and tools were in fact small and portable. Marsh makes it clear that the early machinery was light and delicate and some

"occupy a space of considerably less than six inches each way".²⁰³

Even later machinery was often quite small, simply because of the size of what was being manufactured. For example, the lathes necessary to make screws, arbors and other parts would not have been significantly different in size to their very portable, modern counterparts.

201 Marsh [2], page 15.

202 Harrold [1], page 584.

203 Marsh [3], page 55.

About the only large items would have been the power plant, the transmission and the machines used to *make* the watchmaking machinery. But even much of the heavy machinery used to make the watch-making tools was probably quite small and portable. Lathes, metal planes and other machinery to make objects the size of those specified by Japy and Ingold need only be a few feet in dimension and could have been moved by some people and horse-drawn carts.

Anyway, there was not much machinery. Even if every worker had his own machine there would only be 75 to 100 machines.

Third, Rice wasn't acting in isolation and the "cash value" of what he took was not the only consideration. The shoemaker was acting with Edward Howard, who knew full well that such machinery was very time-consuming and expensive to make, and that the Waltham factory was the *only source* of such machinery. It is clear that Howard wanted to continue making watches, and when he and his "front man" Rice failed to get the buildings they were still in a very good position. They simply moved as much as they could back to Roxbury. Crossman summarises the situation:

"After the failure in Waltham, Mr. Howard anticipated buying in the property and continuing there ... but the amount bid far exceeded their expectations and he returned to Roxbury ... and started up the old watch factory ... The watch factory was now conducted by Mr. Howard in the interests of Mr. Charles Rice".

*"Mr. Howard commenced in Roxbury with a force of some fifteen workmen, the greater part of whom had come with him from Waltham. Work commenced at once on the tools and machinery that were necessary, aside from those which Mr. Rice brought from Waltham."*²⁰⁴

Some new tools and machinery were needed because Howard designed a radically different watch from that made at Waltham. However, much of the machinery of that time would have been quite simple and so readily adaptable, and it is highly likely that many of Howard's new tools and machinery were built from those rescued from Waltham.

And finally Robbins himself, in an address to the Watch Factory Foremen's Association quoted by Marsh, states that

*"the bidding proceeded by a hundred dollars at a time, until my principals, much to their alarm and disgust, became the owners, at the price of \$51,000, I believe, plus a mortgage of \$7,500. We found we had got the wooden buildings, **but not much besides** ... However, with a few grimaces, we shouldered*

our burden and determined to make the best of it" (my emphasis).²⁰⁵

And he goes on to say that in 1857

*"I kept the factory going, principally in the construction of tools and machinery."*²⁰⁶

However, Robbins was actually more precise, and in his speech he said

*"Most of what little machinery there was and most of the stock in process which we thought we had bought, had been carried off the night before the sale, **and the balance the night after**, by parties whom I will charitably say were unknown to us".* (my emphasis)²⁰⁷

Although Robbins may not have had any rights over the machinery and stock removed before the auction, he would most certainly have felt he owned whatever was in the factory after the sale, and

"Mr. Robbins started legal action against Mr. Rice and Mr. Howard. The suit was settled by return of some of the material [but apparently not machines]".²⁰⁸

As I have noted, the buildings would not have been completely empty. The engine house, transmission shafts and furniture would have been in place, and perhaps some large and heavy machinery used for tool making. But there can be little doubt that Robbins had bought a near empty shell together with responsibility for some 60 unemployed workers who were left behind by Howard and who still lived in Waltham and the Improvement Company houses.

I expect one of the main reasons for supposing Howard and Rice had left machinery behind, is the problem of explaining how Robbins got the factory back to work. But I believe there would have been sufficient *non-company* tools around. It must be remembered that the original Roxbury factory was based on employing journeymen watchmakers. But during their apprenticeships, such people bought and made a set of *personal tools* with which they worked. As a House of Commons report notes, in times of desperation workmen pawned their own tools to get money for food. But having done so, they could no longer work at their trade.²⁰⁹ Although this report is forty years earlier, the same system existed, almost unchanged, into the twentieth century. And the Waltham factory was established on the basis of transferring the Roxbury equipment and *skills*. Indeed, Marsh makes a point of stating that:

"Having found a satisfactory location for the factory, the next thing was to make it evident to the employees that country life was a thing to be greatly desired. Accordingly, Mr.

205 Marsh [1], page 12.

206 Marsh [1], page 12.

207 Robbins [1], page 2.

208 Hawkins, page 1.

209 House of Commons, pages 6, 37, 62.

204 Crossman [1], page 55.

*Dennison used to plan excursions into the country, the objective point, of course, being a certain pasture on the south bank of the Charles River. And then he would endeavor to awaken in his companions a little of the enthusiasm which always seems to have possessed him by pointing out to them some of the very charming locations on which to build houses".*²¹⁰

And so part of the tooling of the Waltham factory belonged to the employees and could not have been removed by Rice (the employees had probably removed them to the safety of their homes before that time anyway). In which case Robbins would have had little difficulty in finishing the stock returned by Rice and Howard. But watchmakers did not have their own machines, like wheel-cutting engines, and we can be sure that he had no way to make *new* watches; the machines and tools for basic operations being certainly part of the company's chattels.

There are three further points to note.

First, there can be no doubt that the "fifteen workmen" who went back to Roxbury would have been amongst the most highly skilled at Waltham, and they were almost certainly mechanics and skilled watchmakers. So the biggest problem facing Robbins would be getting mechanics to build new machines.

Second, *Dennison stayed behind*. Why? After all, his partner, some of the best workmen, much of the material and most of the equipment had gone back to Roxbury. So what prompted Dennison to remain in Waltham? This is the second time something peculiar had happened to him, the first being the relationship with Stratton some years earlier.

One likely reason for Dennison staying at Waltham is that Howard did not want him. If we consider Howard's experiences with Dennison in the seven years from 1850 to 1856, we can see a succession of disasters. Howard found out that Dennison couldn't build effective machinery, couldn't design watches, and his "system" of watchmaking had collapsed in bankruptcy.

There is good reason to believe that Dennison was a "difficult" person. In addition to a probable rift with Howard, there are the documented conflicts with Stratton and Robbins. And Moore notes friction between him and William Keith, who was "*very critical of Dennison's methods*".²¹¹ Both Moore and Tremayne mention that he was called the "*Boston Lunatic*" because of his schemes for manufacturing watches,²¹² but such an epithet is indicative of the person as well as his ideas.

However, Howard may have wanted Dennison to come with him, but did not take him because he wanted to be paid far too much.

It is apparent that Dennison had an inflated view of his importance and value. His brother, E.W. Dennison, wrote:

*"Previous to the sale, Messrs Tracy & Baker who were the largest creditors arranged to purchase the concern and also beforehand arranged with my brother (ALD) to conduct the manufactory at 1/3 profit".*²¹³

Which explains why Tracy wrote:

*"Before the assignment Dennison & Howard had differences as to how or in what manner they should proceed. Howard wanted Rice to get possession [he wanted the chattels], but Dennison strenuously opposed and he came to Baker and me to become purchasers".*²¹⁴

There can be little doubt that Dennison was playing one group off against the other to get the best possible outcome for himself.

But E.W. Dennison's description is certainly wrong, because it amounts to Tracy & Baker making Dennison an equal partner, but without Dennison contributing any capital or taking on any of the risk. Dennison himself gives a much more realistic picture:

*"I was to have the general superintendence of the business and to have 5 pr ct. on the manufacture with a guarantee that the same should not fall below 3000\$ a year and there was a dead certainty in my mind that with any decent management of financial matters, I should realize from 4 to 5,000\$. This is just what I felt was my just proportion of the business".*²¹⁵

Dennison's manoeuvres to maximise his personal gain almost failed, but fortunately Robbins needed him. With no experience of watch making and having to get a factory up and running quickly, Robbins had no choice but to cave in to Dennison's demands. E.W. Dennison wrote:

"You can imagine his disappointment when on his return from Europe, he was met with a proposition to assume the superintendence for \$1000 a year, Mr. Robbins disowning any arrangement with Tracy & Baker to the contrary - of course this offer was rejected as pitiable - Mr. Robbins increased his offer to \$1500, then \$2000 and finally \$2500 was fixed upon. ... My brother was reduced to almost the extremity at that time that he is at the present moment ... for which reason he was forced to take the above pittance."

210 Marsh [2], page 4.

211 Moore, page 29.

212 Moore, page 3; Tremayne, page 2.

213 Dennison [2], page 2.

214 Tracy, page 15.

215 Moore, page 23.

The suggestion that Dennison's rate of pay was an insult is patently silly, because \$2500 was about *eight times* the rate for skilled watchmakers and a substantial income.

Despite Dennison disliking Robbins and considering such a low wage an insult, he had burnt his bridges and had no option but to accept. So it is hardly surprising that these two men had little respect for each other, and hardly surprising that Robbins got rid of Dennison at the first opportunity.

Howard went back to Roxbury, designed a new watch, built and modified machinery, and started producing small numbers of high grade movements using the same methods that had been used at Waltham; in 27 years from 1857 to 1884 Waltham produced 2,356,000 watches while Howard produced about 125,000 movements in 44 years.²¹⁶

Marsh offers an interesting insight into Howard's activities:

*"[Howard] soon started a second watch factory in the building in which he was manufacturing clocks. The machines and tools which he used were **practically like those used at that time in the Waltham factory**, and do not seem to have been essentially modified during the entire life of the factory. It is generally, and doubtless correctly understood, that at no time was he able to obtain any profit from watchmaking, but that the losses in watchmaking were more than covered by the profits of clock manufacturing. It was Mr. Howard's aim to produce high grade watches, but the accomplishment of that end involved the work of **skilled watchmakers** to eliminate the original manufacturing defects, and so much labor and expense were involved in the production of the watches of desired high quality that their selling price did not insure a profit"* (my emphasis).²¹⁷

This provides further confirmation of my description of events. Rice did remove most of the machinery from Waltham. The machinery was dumb, produced parts which were not interchangeable and required skilled journeymen. And the excessively high number of man-days per watch inherent in such machinery made it impossible to produce watches profitably.

And third, we must view what happened in the light of what had been achieved before and after the bankruptcy. As I have pointed out in Appendix C, the pre-bankruptcy factory could only produce watches at a rate of about 18 man-days per movement, but the post bankruptcy factory could make one about every 5 man-days (Appendix D). Such a dramatic change could not have occurred if Robbins simply continued on with

inherited workmen and tools, and it requires a significant difference in the methods used from 1857 onwards.

This significant change was made possible by Charles Rice gutting the Waltham factory before it was sold.

There is an interesting consequence. If we draw a genealogical tree of watch makers then Dennison and Howard gave birth to only one descendant, the Howard Watch Company. What was to become the great Waltham Watch Company had a virgin birth in 1857, in an empty building. Indeed, Howard

*"regarded his own firm, and not that of Appleton Tracy & Co., as the rightful successor to the Boston Watch Co".*²¹⁸

Farewell To The Watchmaker

Although the empty factory was vital, it was just an empty factory that had to be filled. Most importantly, a *new management* was needed to decide what to do and how to do it, while the 60 odd journeymen watchmakers were finishing off the old stock.

Which brings us to the second requirement for the post-bankruptcy success:

The key managers were business men and mechanics, not watchmakers.

First Robbins, who was a business man and not a watchmaker. Moore and Priestley note that

*"Robbins was familiar with the English trade - in 1841 he had worked for his uncle, Chauncey Robbins, in the Birmingham, England, firm of Robbins & Martin as head of the watch department [at age 17]. By 1846 at the age of 22, he was back in the US in New York importing watches ..."*²¹⁹

So although he was technically ignorant, he had a strong business interest in watches. What we do know, from Moore's book, is that Robbins was a consummate business man and an excellent administrator who ran the Waltham plant with great skill, very quickly turning it from a failure to a resounding success.

Second, sitting in a near empty factory, with little knowledge of watchmaking, the first task facing Robbins was to make the machinery necessary to manufacture watches. He knew even less about machinery than watchmaking and, either by sheer luck or a stroke of genius, he employed Ambrose Webster as his head mechanic; he was the first machinist hired.²²⁰

Webster had been an apprentice in the machine shop of the Springfield Armory. He then worked for the Springfield Tool Company where, in 1855, E. A. Marsh worked with him as an apprentice.²²¹

218 Geller [2], page 1.

219 Moore, page 26; Priestley [1], page 103.

220 Abbot [1], page 79.

221 Marsh [1], page 15; Hoke [1], pages 189-191; Abbott [1] pages 77-79.

216 Geller [2], page 1.

217 Marsh [4], page 10.

In 1857 he was hired by Robbins, and Webster himself states:

*"My first acquaintance with the Waltham factory was in May 1857 [immediately after Robbins took over]".*²²²

And when

*"Mr Webster took charge of the machine shop of the Waltham factory it was as crude as could well be imagined. There was absolutely no system, no appreciation of the fact that the machine shop was the foundation of the manufactory. The proprietors [Dennison and Howard] had not learned that to successfully run a factory they must build up a machine shop large enough, and under a competent head, to build and repair all the tools and machines needed in the business. Anything approaching an automatic machine was frowned upon. ... there were no less than nine classes of measuring units or gauges, which he changed to one".*²²³

But this quickly changed.

*"Aside from Mr. Webster's abilities as a machinist, he possessed the valuable qualification or ability to realise the imperative need of 'system' in creating and maintaining a successful manufacturing enterprise. [At Waltham] he had his first opportunity to urge the adoption of an initial system ... He also endeavored to emphasize the vital dependence of the entire factory to the Machine Department".*²²⁴

As Collord picturesquely expresses it,

*"[Webster] stood before management and said, 'Listen, you've got to stop regarding the machine shop as a burden to this factory, but rather as the foundation upon which the works will stand.' He went ahead and built the first successful semi-automatic machine used in the factory".*²²⁵

The importance of Webster cannot be underestimated. It is apparent that previous machinists, like Moseley, were competent mechanics, but it seems they did not understand the central role of the machine and the need for "system". Or they simply produced what was asked of them. In contrast, Webster not only understood, but he had the opportunity to implement his ideas.

In the environment of the time,

"the great variety of work which comes to the American boy early gives him practice in solving new problems without considering precedents. He is obliged to face new

*difficulties constantly, and he has no one to appeal to for help ... he cares little for trade practices, for custom, for what is old".*²²⁶

Similarly, Webster and Robbins were forced to solve problems without considering precedents, to make watches without regard for trade practices, for custom, for what was old. They had to begin afresh. And this is undoubtedly the beginning of the long, difficult task of transferring skill from the workers to the machines. A substantial, qualitative change in machinery must have taken place. And this change was initiated and driven by Ambrose Webster with the support of Royal Robbins.

Unfortunately, we know only a little about the tools and machines developed in the period of interest, 1857-1858. Marsh joined Waltham in 1866 and, writing thirty years later in 1896, he says

*"it would be interesting to review the various forms of machines which have successively been used ... such a review is, however, impossible. Most of the discarded or displaced machines have been destroyed".*²²⁷

However, Webster's creativity is well documented and includes the first watch factory lathe with hard spindles and bearings,²²⁸ the first interchangeable parts for lathes,²²⁹ the use of levers to control turning,²³⁰ a semi-automatic escape wheel cutter,²³¹ an automatic pinion cutter (1865),²³² and a train wheel cutter (1865).²³³

Also, there is enough information for us to see something of the changes that occurred.

First, the outstanding 19th century invention that revolutionised watch making was the split chuck followed by the hollow draw-tube lathe. Until its creation, parts to be turned had to be mounted between centers, held on wax chucks or mounted on the face-plate of a mandrel. So the huge numbers of arbors, balance staffs, screws, pillars, canon pinions, barrels and so on, had to be turned using slow, difficult-to-use lathes which required skilled workmen. And so Charles Moseley's invention, which formed the basis of all lathes from that point on, completely changed watch making. Indeed, without it, it is very unlikely that Robbins and Webster could have succeeded.

Abbott, repeated by others, states that the split chuck was invented in 1857 or 1858.²³⁴ Because this idea had such an enormous impact and was so central

²²² Niebling, page 633.

²²³ Abbott [1], pages 79-80; Abbott [2], page 28..

²²⁴ Marsh [1], page 15.

²²⁵ Collord, page 52.

²²⁶ Waldo, page 186.

²²⁷ Marsh [3], page 12.

²²⁸ Abbott [1], page 80.

²²⁹ Abbott [1], page 80.

²³⁰ Marsh [3], page 31.

²³¹ Marsh [3], page 81.

²³² Abbott [1], page 80.

²³³ Marsh [3], page 73.

²³⁴ Abbott [1], page 84.

to manufacturing, it is more likely that the date was 1857.

Abbott's date is supported by Daniel Leary. He started work at Waltham in 1856 as a 14-year old. Describing jewelers he says

*"The chucks we used were steel tapers, sawed at right angles, and a friction collar driven on to hold the jewel ... the draw-in spindle had not then been invented".*²³⁵

However Marsh dates the invention to about 1854:

*"Credit [for the split chuck] doubtless belongs to Mr. C. S. Moseley, who introduced it while the original of the Waltham watch factory was located in Roxbury, Mass".*²³⁶

This may be confusing two inventions. Howard wrote:

*"The most important tool, although a simple one, and which has been of more service than any other one tool in developing and carrying forward watch-making was the spring chuck. That chuck was invented by Mr. Edward Howard, and was used in the clock factory of Howard & Davis sometime prior to any attempt to watch-making".*²³⁷

It is probable that Howard is referring to the chucks described by Leary and not those designed by Moseley, but Moseley's invention was probably derived from Howard's.

There is some doubt about the date of second, well-documented tool, the end-shake tool (described in Appendix B). This replaced the very difficult process of jewelling plates by a far simpler method using an intelligent tool. Abbott provides a biography which is again vague about dates, but it seems Sherwood went to Waltham around 1855 where he was put in charge of the jewelry department and

*"under his charge the jewelry department soon made a complete revolution".*²³⁸

Abbott says he left *"the employ of Mr. Howard in the fall of 1858"*, but he also says incorrectly that the tools were built *"as far back as 1860"*.²³⁹

Small says Sherwood arrived at Waltham in late 1854. He quotes Daniel Leary:

*"[Sherwood] first got up a lathe for opening jewels, then he devised a lathe with tail-stock and spindle, next the caliper rest. ... Mr Sherwood invented the end-shaker, which was considered by all the most wonderful invention that had been made in our business".*²⁴⁰

Unfortunately we do not know *when* he invented it.

It is clear that Sherwood was one of the employees who returned to Roxbury with Howard after the

bankruptcy. In which case the end-shake tool, the last of the three he designed at Waltham, was most likely invented before May 1857. But the dates are critical. If Sherwood left immediately, and remembering that Rice took away the chattels, Robbins and Webster would have had neither the inventor nor the tool. But there is no doubt that the end-shake tool was used at Waltham after the bankruptcy.

Small also states vaguely that

*"Under the combined direction of Howard and Sherwood, first at Waltham and later, following the return to Roxbury, new ideas and systems were introduced, new machines were designed and made".*²⁴¹

However, it may be that Sherwood did not return immediately, but worked at Waltham for a short time after the bankruptcy. Certainly he was still there about May 20, ten or more days after the sale:

*"We learn also, that since the sale of the above mentioned property, efforts have been made to start another establishment of the same kind, either here or in Roxbury, and that a meeting of the employees of the old establishment was called a few evenings since, at the residence of N. B. Sherwood, Esq., for the purpose of ascertaining how many of them would pledge themselves to the interests of the new establishment, and that a very respectable number of the old hands did so pledge themselves, including Mr. Sherwood, Mr. Messer, and others".*²⁴²

Although I have no evidence, it is possible that Sherwood, apparently having his own residence at Waltham, would have preferred to stay, but Howard enticed him back to Roxbury, because he paid him

*"nearly double the wages he paid the best of his other employees".*²⁴³

Certainly, as it is the last tool mentioned by Leary, it would have been either shortly before or shortly after the events of 1857. Accuracy in transcribing is critically important. The above quote of Leary separates out mention of the end-shake tool into a separate sentence and this separates its development from the others, implying it was made later. But it may not. Only the person who spoke to him could know.

The endshake tool is central to the problem of non-interchangeable pivots, jewels and arbors which continued until after 1880 and was the reason for the *Record*, Waltham's watch records, described by Jacques David:

"Recording consists of noting in a table the diameters of the 2 pivots of the 5 mobiles ... and the lengths of these pivots. ... Even if a

235 Small [1], page 28.

236 Marsh [3], page 15.

237 Howard.

238 Abbott [2], pages 18-20.

239 Abbott [2], page 24.

240 Small [1], page 28.

241 Small [1], pages 82-83.

242 Waltham [3], page 59?

243 Small [1], page 84.

*movement is to have only top plates jewels, or some mobiles are not to be jewelled at all, the sizes of the pivots are noted ... The Record also notes the size of the impulse pin, or the fork notch, so that a replacement lever or roller can be sent for with the same ease as with pivoted mobiles".*²⁴⁴

Unfortunately David's detailed description of watchmaking, written in French in 1876, was not published until 1992, when it was produced in a limited edition of 1,000 copies. Worse, an accessible English translation did not appear until 2003. However, the Record was described in 1858:

*"The sizes of the several pivots and jewels in each watch are carefully recorded under its number, so that if any one of either should fail in any part of the world, by writing to Waltham, or to Robbins & Appleton, ... and giving the number of the watch, the part desired may be replaced, so as to be a working match."*²⁴⁵

Also, Fitch mentions the Record in what is just a passing comment without any details.²⁴⁶ And Hoke quotes a Scientific American advertisement of 1884 saying that Waltham

*"kept accurate records of all its watches [and] the owner need only send on the number of the movement to enable the factory to supply an exact duplicate" of a part.*²⁴⁷

However, it seems that the full implications of these statements have not been recognised and the Record and the end-shake tool have been overlooked. The implication drawn was that the movement number was only needed to pick an interchangeable part for the correct calibre, rather than enable a non-interchangeable part to be made.

One important point is that the Record did not commence until after the takeover in 1857. This is supported by the preface to a serial number list which states:

*"Around 1900 the company had ledger books prepared from what appears to be inventory cards. The whereabouts of the original cards is not known".*²⁴⁸

These lists commence at serial number 1001, but all are post 1857 watches; see Price for a mention of the re-use of serial numbers below 5000²⁴⁹. It is likely that the original cards were the watch records described by Jacques David and Fitch. Small notes that the E. Howard & Co. instructions for ordering material read

*"in ordering material for any movement numbered below 30,000, always send old parts".*²⁵⁰

Clearly Howard did not record the necessary details for watches before 1879.

A consequence of the Record is that a repair department was necessary, not only for requests from outside, but also to fix problems in production. Although there is little evidence to support my opinion, I believe the Record ceased about 1883 when Ezra Fitch arrived at Waltham and the repair department was probably closed; so there was no longer a reason to record details of watches.

The necessity of this shift of emphasis from watchmaker to business manager and mechanic was recognised from then on, and when Elgin was set up

*"The seven recruits from Waltham became known as the Seven Stars. ... A significant characteristic of the Seven Stars was that five of them came to the watch business ... as mechanics".*²⁵¹

The consequence of this shift in focus was a corresponding shift in employment:

*"The second factor that assisted in the adjustment of the new Company to the trying conditions of 1857 was the personnel policy. When the Company was founded by Dennison, it was recognized that the mechanical problems were difficult and every effort was made to hire the best craftsmen that could be found. Under Robbins ... **workers from old New England families** were given preference when new jobs were filled"* (my emphasis).²⁵²

And he continued:

*"A **considerable number of the factory hands were unskilled workers**, many of them young women who lived at home ... The remainder were largely skilled craftsmen ... Since Waltham was a small town of about 6,000 population, it is probable that many workers were drawn from the surrounding farms"* (my emphasis).²⁵³

These points are reinforced by Moore's comment that:

*"there is no record of serious difficulty from a lack of skilled labour during this period".*²⁵⁴

Which was more to do with the shift to unskilled workers than a sufficiency of skilled journeymen.

Moore also cites John Swinton who, writing about a later time, notes that

244 David, page 60.

245 Anon [1].

246 Fitch, page 677.

247 Hoke [1], page 246.

248 Waltham [2].

249 Price, page 14.

250 Small [1], page xx.

251 Alft, page 13.

252 Moore, pages 30-31.

253 Moore, page 31.

254 Moore, page 29.

*"the workshops are filled by young men and women of the soil, almost wholly of New England lineage".*²⁵⁵

It is here that we see the beginning of the change in employees that was highlighted by Alft and Briska.

From the start, Dennison would have employed a few unskilled workers to perform unskilled tasks such as running errands. But his factory was dominated by trained journeymen. In contrast, Robbins shifted direction and under him preference was given to local farm hands who would have had no knowledge of watchmaking and most certainly never undertook an apprenticeship. But such a shift in employment policy is only possible if there is a corresponding shift in manufacturing processes. Farm hands may be cheaper than craftsmen, but they would have nothing to do unless the processes had been dumbed down by the creation of much more intelligent and sophisticated machinery.

Of course Robbins did employ skilled watchmakers, but the proportion of such people fell. Let us assume Dennison employed 70 skilled journeymen and 5 unskilled people to do other tasks like moving materials around the factory. Then we can conclude that Robbins inherited some 55 journeymen who outnumbered the workers by 11 to 1. Then, once new, more intelligent machinery had been made, they were probably ample for skilled tasks in the increased production. So if the workforce rose to about 100 at the end of 1858 (Appendix D) we can predict there would have been roughly 50 skilled and 50 unskilled employees, a 1 to 1 ratio. And this ratio continued to drop from then on.

Lego Land At Last

As I have stated, the American system is the manufacture of machines by unskilled labour. Well, that is how it started. In fact, it became obvious at a fairly early date that the development of automatic machinery of increased accuracy not only enabled the use of unskilled labour but it also reduced the number of labourers needed. Around 1860 each worker at Waltham could manufacture 50 watches in a year, and by the early 1900s this had risen to around 500 watches for each worker. That is, *fewer* people were needed to achieve the same production.

The process of increasing machine complexity has continued without abatement. Landes outlines the development of the Swatch watch in the 1980s and he notes that

*"the production line ran automatically, and all one saw was robotic hands and pincers tirelessly coming and going and ministering to the components wafted along by the mechanized belt".*²⁵⁶

And this was quickly followed by error detecting systems to automatically weed out faulty modules.

Likewise, at the Seiko plant in Japan

*"a large room, about eighty metres square, filled with many dozens of automatic machines, a moving belt carries components from station to station, assembling watches as it goes. ... The room is almost empty of humans: a few inspectors, mostly women ... a few mechanics ...".*²⁵⁷

At present the production of quartz watch modules is in the billions per year. These watches require no watchmakers and only a few machinists and computer systems engineers. The human has been all but eliminated and production per person must be of the order of a million watches per year.

So at some time watchmaking passed through a stage when increased productivity exceeded demand and consequently employee numbers fell. Of course the relationship between production and employee numbers is far more complex than I am suggesting, but this simple view is sufficient for my purposes, which is to briefly look at post 1860 watchmaking in America.

Not long after the second world war the few remaining American watch companies disappeared and left the market to the Swiss and later the Japanese. On the surface it seems that the American system had failed, for watches anyway. In contrast, the Swiss manufacturers survived through one crisis after another and even the quartz revolution could not kill off their industry, although it went close. What was the difference?

Undoubtedly one factor was relative importance. No matter how much we might admire American watchmaking, it was always a tiny, even trivial part of the American economy, dwarfed by other industries. So, although its continued existence might be a matter of pride, its absence, other than in war time, made not a jot of difference to the wealth of the United States. In contrast, the Swiss industry was a huge part of the economy and entire regions depended on it for their livelihoods. It is hardly surprising that any crisis was met with national concern and frantic attempts to support watch companies.

But more important is an underlying difference in business culture. The United States had developed an attitude to business akin to Darwin's theory of evolution, the survival of the fittest. One aspect of this is the approach to competition and anti-trust laws. The business culture believed that there should be minimal, preferably no impediments to competition, and if companies wanted to engage in price wars they should be allowed to do so. Indeed, they were effectively *forced* into such wars, because any attempt

²⁵⁵ Moore, page 315, note 12.

²⁵⁶ Landes, page 390.

²⁵⁷ Landes, page 391.

to set up a cartel to stabilise prices would immediately bring down the wrath of the law.

This situation, discussed by Moore, meant that the profits of watchmaking companies fell and significant cost-cutting measures were needed simply to survive.

The Swiss political and business culture was completely different, and consequently their reaction to problems were the reverse of that taken in America. For example, after the first world war the Swiss watch industry collapsed, sales dropping from 18 million watches in during the war to around 8 million in 1921, and unemployment in the industry rising to around 28,000. Drastic measures were taken to support the industry, as explained by Landes:

*"The first step was the creation of a number of trade associations ... to defend the interests of makers and sellers of watches. ... The next step was the acceptance, beginning in 1928, of collective agreements governing output, pricing and export policies of all producers in the industry, with provision for enforcement and compulsory arbitration".*²⁵⁸

Even so, the Wall Street collapse produced another depression and, to quote Fallet,

*"At the end of 1929 sales collapsed. The export of machines and tooling, the transfer of labour abroad and the sale of half-finished movements (known as chablons) came to the fore again".*²⁵⁹

More collective agreements were signed and the final step

*"was government intervention ... [creating] a super 'holding' ASUAG ... followed in 1934 by a federal statute giving the watch cartel's private agreements the force of law and imposing new restrictions on output and technique".*²⁶⁰

The Swiss deliberately inhibited competition, controlled prices, and prohibited export of machinery and unfinished watches.

These laws had teeth, as the Oris Watch Company found out:

*"Because of the Swiss Watch statute, protecting the monopoly of a limited number of manufacturers, Oris [was] initially unable to produce precision watches with lever escapements".*²⁶¹

So the company was forced to stay in the low quality, pin-lever market.

Another example is Tissot. To summarise the history provided by Fallet,²⁶² both Omega and Tissot had been weakened by the crisis after World War I

that eventually led to the federal statute legalising the watch cartels. In 1930 Tissot and Omega joined together under the SSIH umbrella. Both remained separate companies, but instead of competing without constraint they co-operated. SSIH, which other companies subsequently joined, was the final expression of an agreement reached in 1924. This agreement not only included production co-operation (in 1925 it was arranged for a new Omega calibre to be made by Tissot), but administrative collaboration as well, with Omega appointing Paul Tissot as a director. A later example is that the Omega Speedmaster movement was designed and manufactured by Lemania, which had also joined SSIH²⁶³.

As well as the prevention of cartels, the American business culture has another aspect. This is that the needs of shareholders is often in conflict with the needs of the company and its customers. A basic tenet of private industry is that it should return an adequate compensation to shareholders through dividends, as payment for their provision of capital. Generally, company boards take a long-term view and balance dividends against company viability, preferring to reduce dividends at times when the company needs capital for survival or development. But the lack of constraints inherent in a free market economy allows boards to give preference to the short-term demands of shareholders, even if this risks long-term existence. At its extreme, this becomes asset stripping, where cash is depleted and even fixed assets are sold to boost dividends, until the company goes bankrupt. Companies are most in danger when a single person has a controlling interest, which was the case with both Robbins and Dumaine at Waltham. Landes provides strong evidence (supported by indirect statements by Moore) that Dumaine asset-stripped Waltham for personal gain, and sold the company just before it collapsed.²⁶⁴

Although this divergence of cultures goes a long way to explaining why the American watchmakers failed, there is a much more important factor. *The Americans stopped dumbing down.*

Unfortunately, the only company for which there is sufficient information is Waltham. But in that case there is some striking and all but conclusive evidence. Perhaps the clearest is a statement by Henry Fried:

*"Some of the earlier machines were so efficient and advanced that I saw them still in use at the Waltham factory in the 1950's when I used to visit there".*²⁶⁵

Although this is a testament to the designers and machinists, it is a damning condemnation of management. Whereas the Swiss industry continually advanced, with a never-ending stream of new machine

258 Landes, page 353.

259 Fallet, page 152.

260 Landes, page 353.

261 Oris, page 12.

262 Fallet, pages 151-160.

263 Omega, pages 36-42.

264 Landes, pages 356-360.

265 Marsh [3], page 6.

designs and techniques, Waltham had stood still, relying on outdated equipment and ideas. The Swiss, and later the Japanese competition may have eventually crushed Waltham, but management made sure it had no chance.

Again, Moore's chart of man-days per watch hides important features. Although only a rough approximation (but better than Moore's idealised, smooth curves) and simply to give a comparison, Figure 11 displays the main events.

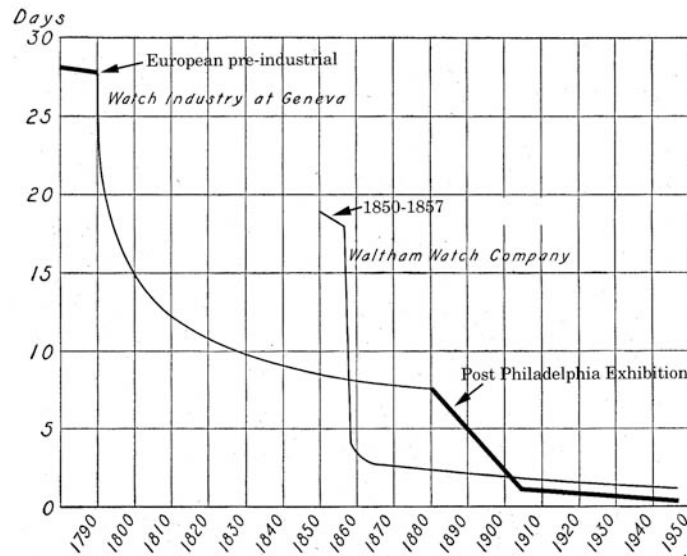


Figure 11

Not long after 1876, the shock and knowledge, brought back to Switzerland from the Philadelphia Exhibition by Jacques David, started having an impact. At that time, the rate of production in Switzerland was 40 watches per year by each workman (about 7.75 man-days per watch), as against 150 (2.1 man-days) in America.²⁶⁶ The Swiss changed direction from craft based comptoirs to machine based factories. And so the man-days per watch fell in Switzerland to match the American factories. But it did not end there. Unlike the Americans, who had a captive market and little need to improve on what they had done so successfully, the Swiss continued along the path of dumbing down. Machines with more and more sophistication and intelligence were developed to increase productivity and lower costs. Most importantly, while the American industry was still based on the railroad pocket watch, the Swiss took to wrist watches with a vengeance.

The trouble at Waltham, which is analysed with care by Moore, dates back to the death of Royal Robbins in 1902 and Duane Church in 1905. Moore notes that

*"the management of war and business is normally conducted along purely autocratic lines".*²⁶⁷

²⁶⁶ Fitch, page 677.

²⁶⁷ Moore, page 91.

and he points out that Robbins

*"was a dictator only by virtue of [the shareholders] unfailing confidence in his ability".*²⁶⁸

But after his death, the new management lacked ability and lost direction. Eventually, when Dumaine took over, management moved from ruling for the benefit of the company to ruling for some other source of gain.

To make this clear, let me quote from Moore:

*"When the company was founded in 1850, it was purely a research organization. Dennison had an idea ... but he had neither the process nor the equipment. ... The new plant was built at Waltham in 1854 and ... the erstwhile inventors took over the responsibility for production and also continued with their search for better equipment and methods".*²⁶⁹

Although glossing over the discontinuity which occurred in 1857, this is a fair enough summary of what drove the company in the early days. Moore continues:

*"Dennison left the company in 1861, but it continued to be dominated by inventors: Ambrose Webster, Fogg, Vander Woerd, and others. This state of affairs continued until the promotion of Ezra Fitch to the position of general manager in 1883 brought a marked change in general policy; then the inventors ... had to subordinate their wishes to the dictates of the Sales Department. Notwithstanding ... the inventors remained in positions of authority in the factory and continued to exert a powerful influence on Company affairs".*²⁷⁰

The last date in the NAWCC copy of the watch records kept by Waltham is 1883,²⁷¹ and it might be supposed that this indicates Waltham achieved full interchangeability at that time. However, Ezra Fitch took over in 1883 and it is more likely that the record ceased as a result of cost cutting measures. As Jacques David points out, Waltham maintained a repair department, without which there would have been no point in keeping watch records. It is probable that Fitch closed down this expensive service and Waltham ceased to provide individualised spare parts, handing over the problem of fitting parts to retail watch repairers.

Moore's choice of the words "research" and "inventor" are excellent. Throughout these early, vibrant years, Robbins kept the focus on these crucial machinists, all of whom were employed after 1857. That is, he made the continual and progressive dumbing down of watchmaking the prime goal of the company. A

²⁶⁸ Moore, page 91.

²⁶⁹ Moore, page 237.

²⁷⁰ Moore, page 237.

²⁷¹ Waltham [2].

dumbing down achieved by increasingly sophisticated automatic machines working to increasing accuracy.

In the 20 years from 1860 to 1879 Robbins spent about \$3.482 million on machinery (including some furniture and fixtures), an average of about \$174,000 per year.²⁷² In contrast, Moore notes that Dumaine spent \$1.288 million on new machinery in the 20 years from 1923 to 1942, an average of about \$65,000 per year or 1.5% of the value of machinery.²⁷³ Kenison (quoting William Kilbourn, a division manager under Dumaine) notes the single motor, shafts and belts used to drive all machines were replaced by individual electric motors on each machine and the floors were replaced throughout the factory.²⁷⁴ But there is no indication of how much of the \$1.288 million this took and hence how much was actually spent on retooling.

Also, there is no allowance for inflation in these raw figures, and the decreasing value of the dollar between 1860 and 1942 means that the difference, in real terms, is much, much greater. For example, in today's money Robbins spent \$3,827,762 in the year 1879 and Dumaine spent \$81,823 in 1942; so Robbins invested nearly 47 times more than Dumaine on machinery. Even if nothing else had changed the amount spent by Dumaine is alarmingly low, but as he switched Waltham from making pocket watches to wrist watches, which would require substantial retooling, it is patently ridiculous.

Moore, attempting to show Dumaine in a good light, offers a different explanation:

*"The available data do not warrant any conclusions as to the adequacy of this rate of replacement. The rate of obsolescence on watch-manufacturing equipment may be much lower than is the case for other industries. Visitors to the Waltham plant are shown equipment in operation which is reputed to have been designed fifty years ago by Church. The continued use of this equipment is a tribute to Church's genius, but it may also signify that further improvements in this old and highly developed industry are too difficult to be profitable. Where progress has been very rapid, it may be advisable to rest until the associated mechanical arts have made parallel advances".*²⁷⁵

This is shown to be a feeble excuse by an anecdote given by Kenison, which deserves repeating because it reflects the inherent problems at Waltham:

"New England in the 1930s was a leader in medical advances, just as it is today. Apparently one of our best known surgeons had come up with an idea to save a certain kind of brain injury patient through a revolutionary surgical procedure. It required the sewing of a very small severed nerve in the brain. The doctor needed a very small gold needle that would allow the nerve to be sewn together in much the same way as a seamstress would work on a hem. Massachusetts General Hospital contacted F.C [Dumaine] on the theory that if such a needle could be made, Waltham Watch could do it. It took three months and the only way the eye of the needle could be constructed was to taper the 'fat end' and bend it around into a loop. The needle worked, the operation was successful and the patient lived a normal life. Everyone involved with the project was proud of Waltham's accomplishment.

*"The 'Old Man' had a needle packaged and sent to one of the heads of the watchmaking industry in Switzerland, together with a newspaper account of its creation and success. Also included was a note offering the following challenge: 'Match this if you can'. About 90 days later a package from Switzerland arrived. It contained Waltham's needle split laterally three ways, drilled and threaded. No note accompanied it".*²⁷⁶

This clearly demonstrates that Waltham's machinery and research skills were sadly out-of-date and inadequate as early as the 1930's.

One company, Hamilton, lasted longer, going out of watch production in 1969, and its survival makes an interesting comparison. First, during the Second World War it was the only company to successfully manufacture marine chronometers. Not only did Waltham and Elgin fail ignominiously, but Hamilton designed arguably the best marine chronometer ever built. Second, the company produced a number of striking and sophisticated wrist watch designs. And third, it diversified into other precision engineering areas. The inescapable conclusion is that Hamilton maintained a focus on research and development long after other watch companies had opted for stagnation and death.

272 Hoke [1], page 249.

273 Moore, page 197; Landes [1], page 358.

274 Kenison, page 192.

275 Moore, page 232.

276 Kenison, pages 181-182.

Appendix A: Operations To Make A Full-Plate Movement

Calibre Features

It is not possible to understand watch manufacturing without some knowledge of the design of movements and how they are made, and this monograph requires the reader to have at least a basic understanding of a key-wound American full-plate watch with just a going train, 7 jewels and no complications. Whether made by hand or by sophisticated machinery, the parts and the problems remain the same. The only significant variations result from the layout of the train and the design of the two plates.

Detailed descriptions of how to make a watch by hand are given by Berthoud & Auch²⁷⁷. Because they are concerned with the typical continental verge watch, a few things they describe are not relevant, but the majority of the steps apply to almost any watch.

The form of the top and pillar plates of a full-plate watch are dictated by two constraints.

First, the barrel is made as large as possible and extends from the outer edge almost to the center. Consequently *at least* one wheel, the center wheel, overlaps it. In order to keep the movement reasonably slim, it is normal to cut a recess into the middle of the pillar plate so that the center wheel can run underneath the barrel. Otherwise the barrel must be held away from the pillar plate, by a shoulder on the barrel arbor, to leave room for the center wheel; Price illustrates such trains²⁷⁸. Also, to make the mainspring large and strong enough, the top plate is cut out and a barrel bridge mounted on it, so that the barrel can be higher.

Second, the size of the center wheel means that the balance staff cannot go through to the pillar plate and it must be supported by a potence attached to the underside of the top plate.

Because the center-wheel is sunk below the level of the pillar plate, the third-wheel pinion must be sunk even lower. Although there are many variations, a common arrangement is to cut an *eccentric* hole in the pillar-plate and cover it with a train bridge mounted on the outside under the dial. Then the third-wheel is placed under the center wheel and the fourth-wheel pinion placed beside it. Although Figure A1 is of an English fusee movement, it clearly shows this arrangement; **d** is the center-wheel, **e** the third-wheel, **f** the fourth-wheel, **g** the escape-wheel pivot and pinion hole, and **h** the lever pivot hole. The hole in the plate for the train bridge can be made as 2 circular holes or

an irregular shape; either way, turning it on a lathe is not simple.

Many books have photographs of early American watches and contemporary English watches, but they only give top plate views. There are no books that provide adequate illustrations of the internal arrangement of the train or the insides of the plates. Unfortunately I do not own a suitable American movement to photograph, but fortunately Price provides a dial side view of the pillar plate of an early American watch (Samuel Curtis No. 899) showing the train bridge, Figure A2.²⁷⁹

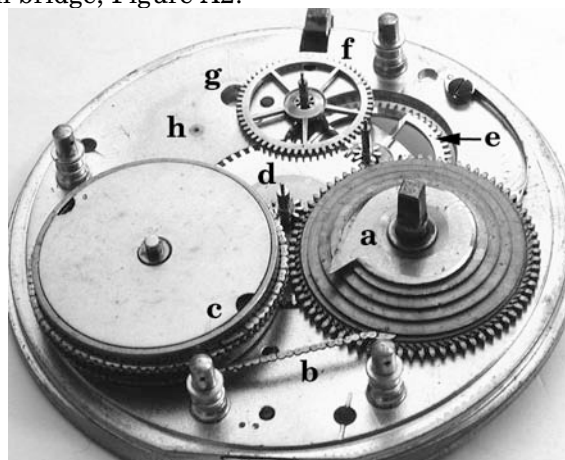


Figure A1

To a large extent, the positions of the four pillars are dictated by these features and they are arranged asymmetrically.

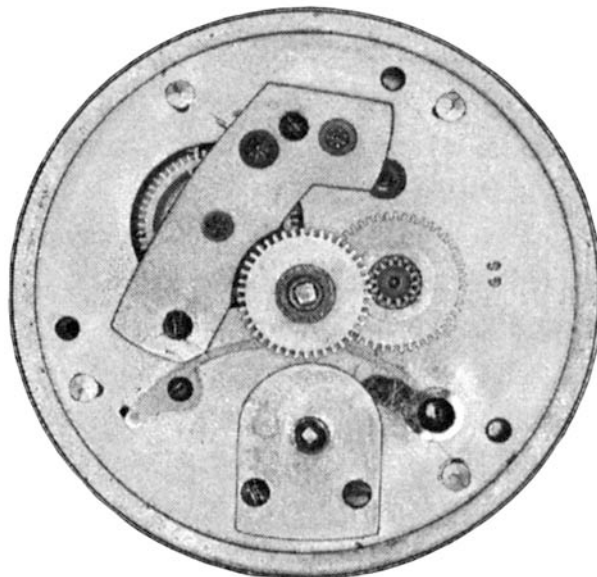


Figure A2 (Reproduced from Price, page 7)

²⁷⁷ Berthoud.

²⁷⁸ Price, page 5.

²⁷⁹ Price, page 7.

Although the center wheel is normally recessed into the pillar plate, it is possible to position the other wheels between the plates. However many early watches made at Roxbury and Waltham retain the train arrangement which requires a cut out pillar plate.

Unfortunately, Price does not provide details of the Model 57 train arrangement, but I assume it is similar to that shown in Figures A1 and A2. (The Model 57 was the basis for post-bankruptcy watchmaking. However, it is not clear if there was one Model 57 calibre or an evolution of number of similar calibres.)

Finally, the balance cock and balance always cover the center of the top plate. Consequently these watches, which are key wound and set, have the hands set by a square on the cannon pinion. Setting from the back instead of from the dial side did not become general until the introduction of three-quarter plate movements, where the balance is planted at the edge of the plate instead of in the center.

Total Operations

The parts that make up a watch movement and the number of operations required to make them are based on the table at the end of this appendix. This table was constructed by examining a movement, noting down all visible components and estimating the number of operations to make each part. In addition to listing parts, the table gives the number of plain holes (P hole), threaded holes (T hole) and pinions. Note that not all arbors have pinions and not all pinions have arbors.

The total number of distinct parts is 102.

The number of operations depends on the methods used. For example, if a pin is simply pushed into a hole and riveted there are fewer operations than if the pin is threaded, the hole tapped and then the pin is screwed in and riveted. I have tried to be conservative in estimating the number of operations.

I have divided the operations into 7 groups. In order from most to least frequent they are:

- (a) Teeth cutting (360, 33.6%): Cutting teeth on the barrel, train, motion-work and barrel ratchet using a wheel-cutting engine.
- (b) Turning (305, 28.4%): All operations done on a lathe. Some of these involve eccentric turning requiring a face plate or a wax chuck.
- (d) Shaping (177, 16.5%): Shaping parts which cannot be turned; for example pins, screw slots, the barrel click and the potence. These parts require special treatment by filing or cutting to produce their correct form.
- (c) Drilling (134, 12.5%): Drilling and counter-sinking holes. There are 102 holes. Some holes have steps (for example, to countersink screws) and I have included oil sinks here.
- (e) Thread cutting (52, 4.8%): Cutting threads on the 26 screws and in their holes.

- (f) Riveting (27, 2.5%): Attaching pillars, steady pins and so on.
- (g) Punching (18, 1.7%): Punching out flat pieces with presses and dies. This includes the plates, wheels, etc.

Thus a total of 1073 operations are required to make the 100 parts. This is a good estimate, not an exact figure. Some variations in design, such as having 2 screws to hold the potence, and minor errors in my calculations mean the figure may be a little smaller or larger. However, the *relative* number of operations in each group is unlikely to vary much.

A large number of tools are needed. Different teeth cutters are required for each wheel; most holes need drills of different sizes, each punching operation requires a different press and die; and so on.

Also, I have not attempted to estimate the relative difficulty of operations. For example, drilling is much easier to do than turning, which is easier than shaping. So the amount of skill and time varies considerably.

Finishing

Nearly every operation performed in making a watch has to be followed by one or more finishing operations. Some examples are:

- (a) Drilling: The holes usually have burrs that must be removed, and many holes need to be smoothed internally.
- (b) Turning: Most turning operations do not produce a perfect surface, so grinding or smoothing and polishing is necessary.
- (c) Shaping: Irregular shapes have to be formed using files or special cutters and they then need finishing. The barrel click spring, for example, can only be roughly shaped at first, after which it must be hardened, tempered, thinned to the right strength and then polished.
- (d) Bluing: Steel parts are polished and blued not only for appearance, but also to inhibit corrosion.
- (e) Gilding: All brass parts are gilded to prevent corrosion. This involved meticulous cleaning, preparation of the surfaces and then gilding. After which, because the gold is deposited on all surfaces, all holes have to be cleaned out

A conservative guess as to the amount of finishing involved is to *double* the basic number of operations.

As a result, the total number of operations including finishing is about 3,219.

Note that I have omitted all indirect operations; for example, engraving, the fact that the movement is assembled twice, before and after gilding, and adjusting.

The above figure fits very well with Marsh's total of over 3,700 operations²⁸⁰; much of the difference will be

280 Marsh [2], page 13.

due to the later addition of keyless work and compensation balances, and to changed methods, for example machining pinions instead of making them from pinion wire.

Screws, Pins and Holes

There are about 26 screws of different sizes. Each screw requires a number of operations performed on a piece of steel wire held in a lathe:

- (a) Face the end of the wire. If the end of the screw is visible it is often slightly domed rather than left flat.
- (b) Turn the body of the screw to the required diameter.
- (c) Cut the thread with a die.
- (d) Turn the head the required diameter.
- (e) Cut off the screw and face the head.
- (f) Cut the slot in the head.

In addition, the head (and end if visible) must be ground and polished. If necessary the screw is then blued. So there are about 182 operations to make the 26 screws.

In addition to screws there are about 22 pins:

- (a) *Steady pins*: When a sub-plate, such as the balance cock, is attached to a plate there are two steady pins. These pins should be called alignment pins because they hold the sub-plate in the correct position; the screws are generally quite free in their holes and cannot be used for alignment. These pins are quite thick and can be turned and cut off in a lathe. They can be made slightly tapered so that they are forced into the corresponding hole and riveted. Or they can be threaded like a screw, put in and riveted.
- (b) *Joining pins*: Pins can be used instead of screws to join parts together; for example, early watches had their dials held on by tapered pins running through the dial feet. These pins are generally very thin and cannot be turned.
- (c) *Other pins*: A few pins have different functions. For example, I have included as pins the stud for the minute wheel, the guard pin on the lever and the hooks on the barrel and its arbor for the mainspring; all of which start life as pins.

Although obvious, it must be remembered that for each screw there are two holes, a plain hole in the piece to be attached and a threaded hole. Some of these holes are stepped so that screws can be countersunk and so they cannot simply be drilled.

There are about 103 holes in a watch, including pivot holes, but because some are stepped at least 121 operations are required to make them.

To drill the holes for pivots and other attachments it is essential that there be some method of aligning the

partially completed plates and sub-plates accurately. The holes have to be in the correct positions and upright; for example, the holes in the top plate must be perpendicularly above the corresponding holes in the pillar plate. The holes have to be drilled as most are far too small to punch. And after drilling they must be deburred and smoothed.

The tolerances for pivot holes, both in position and diameter are very small. The old method, used in hand work, was to drill pilot holes in approximate positions and later to plug these holes and re-drill them. This was necessary because of variations in wheel and pinion diameters and in the size of their teeth.

The only practical way to drill pivot holes in sub-plates is to first attach the sub-plates to the top and pillar plates. So they need to be clamped in position and the holes for the steady pins and retaining screws drilled; then the steady pins turned, threaded, inserted and riveted in place.

To locate holes correctly, some form of master plate is necessary. This plate could have small, raised points to mark hole positions on the plates, which may be the method used by Japy, or it could be drilled through with guide holes. Either way there has to be some way to accurately align the watch plates with the master plate.

If the plates are plain blanks then there is no problem. The two plates are simply clamped together and *all* holes drilled at the one time. This method means that the holes for the barrel and train bridges must be marked and cut out later; they cannot be punched out first. If the plates already have asymmetric features, such as the bridge or pillar holes, then there must be a very good alignment system. The four pillar holes can be used for this purpose because they are disposed asymmetrically around the edge of the plates and so provide a unique reference system. However, as I have already noted, the tolerances for pivot holes is very small and the pillar holes must be very accurately located and reamed out to an exact size.

The Top Plate And Its Attachments

Given suitable dies, it would be possible to punch out the top plate with its eccentric hole for the barrel; there is no strict size requirement for the hole and so it could be punched fairly easily. However, with the possible exception of the holes for the pillars, the other holes must be drilled; fine, hard steel pins to punch out small holes would snap off the dies and the holes would be poorly formed. Other than drilling these holes, tapping some for screws and any necessary finishing, the top plate is complete.

There are five pieces attached to the top plate:

- (a) Balance cock: This could probably be punched out, but it has a vertical profile that must be turned. To hold it while turning requires a wax chuck or special clamps. Both the jewel

and screw holes are countersunk. It has two steady pins.

The balance jewels (and plate jewels if there are any) are mounted in chatons. As the jewels were purchased they may have already been mounted. However the chatons would have to be turned to fit the holes in the cock, potence and plates.

- (b) Barrel bridge: This is punched out. It has two countersunk screws and two steady pins. Attached to it is the dust guard which would be turned from brass rod.
- (c) Potence: The potence, which holds the lower balance-staff jewels, is similar to the balance cock, having a foot and a raised section holding the jewels. Thus, although it may be possible to punch it out, it has a profile that must be turned or filed. There are two steady pins and one or two screws.

The potence must be positioned so that it does not obstruct any arbors and the end of the lever can reach the roller jewel.

- (d) Regulator: In the watches we are considering, the regulator consists of a steel bar ending in a large, split circle, Figure A3. The split circle clips into the hole in the top plate which surrounds the balance staff. The rod is thinned and flattened from this circle to outside the diameter of the balance spring, and two small steel pins inserted in it, the curb pins. The remainder of the rod is often rounded on top and tapered to a rectangular block, left there for moving the regulator by a finger nail or tool. The end of the rod tapers to a point over the index scale (either engraved in the top plate or an engraved arc of steel screwed to the plate).

Because of its shape, this piece, made from hardened and tempered steel, is very difficult to make. As can be seen from Figure A3, it has a very complex profile. The underneath of the split ring is tapered and it fits into a correspondingly tapered hole around the balance staff; this is essential to hold the regulator in place. The tip, which the pointer to the regulator scale on the top plate, is rounded on top. And the entire piece has been polished.

The only way to make the regulator, before sophisticated machine tools, is by hand filing, grinding and polishing. It is quite likely that they were imported from England.

Note that this regulator is for an undersprung watch where the balance-spring is between the balance and the top plate.

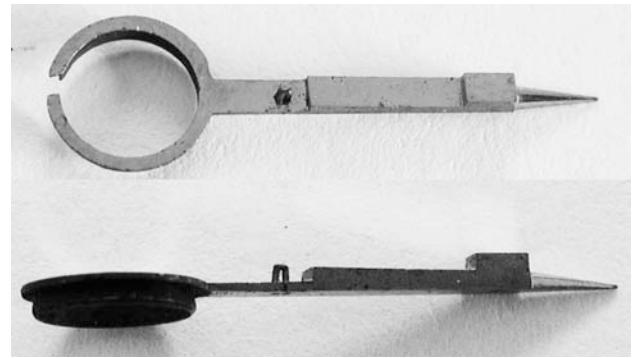


Figure A3

- (e) Balance spring: The balance spring is often attached to the top plate by a simple round or square stud with a pivot that fits friction tight into a hole in the top plate. Although easy to make, it has the disadvantage that it is difficult to remove the balance spring for servicing. Figure A4 shows a much better stud which is attached to the top plate by a screw and one steady pin. Although making it much easier to handle the balance spring it is difficult to make.



Figure A4

The collet, to attach the balance-spring to the balance staff, is turned from a drilled brass rod. Then it is split and the hole for the balance spring drilled through one side.

The Pillar (Bottom) Plate And Its Attachments

The pillar plate and its eccentric hole for the train bridge can be punched out of brass sheet. However, the eccentric hole is often made up of two intersecting round holes, one for the third-wheel and the other for the fourth-wheel pinion. It may be that these are not punched out. Instead the hole for the fourth-wheel pinion is drilled, after which the plate is mounted on a face-plate or wax chuck and the third-wheel hole turned out.

In addition the plate must have a recess for the center wheel, and the whole of the dial side, except for a narrow rim, is recessed to make room for the motion work and barrel ratchet under the dial. These recesses must be turned. (Alternatively, as is common with English watches, the dial side of the pillar plate can be left flat and the dial mounted on a separate dial plate. This dial plate is cut out to provide the room for the under-dial parts.)

With the possible exception of the holes for the pillars and the dial feet, the other holes must be drilled.

There are 7 pieces attached to the pillar plate:

- (a) Train bridge: This is punched out. Its shape is arbitrary except for providing space for two screws and two steady pins.
- (b) Barrel ratchet, click and click spring: The barrel ratchet is a steel wheel squared onto the barrel arbor. In principle it should have ratchet teeth, but often it has ordinary teeth, probably because they are easier to cut. The barrel click has an irregular shape. It might be punched out but it would need finishing, including drilling the screw hole for a shoulder screw. The click spring, as noted above, is roughly shaped and the foot drilled for the screw and steady pin. It is then hardened, tempered and the spring ground down to the required thickness. The click and its spring can be seen in Figure A2.
- (c) Barrel cock: The barrel ratchet can be pinned to the barrel arbor to keep in place. This creates a problem: the barrel cannot be removed to replace the mainspring without first removing the dial and unpinning the ratchet. The alternative is to have the barrel ratchet loose on the arbor and hold it in place by a barrel cock. This cock does not have a pivot hole for the barrel arbor; that is in the pillar plate. Instead the hole in the cock is over size and simply makes room for the end of the arbor. Because the position of this piece is not critical, it has no steady pins and is held by two screws. In principle, it is now possible to remove the barrel without taking off the dial. But personal experience shows that it is almost impossible to put the barrel back in, because the ratchet inevitably moves and no longer lines up with the square on the arbor.
- (d) Pillars: Pillars are turned from brass rod. One end has a pivot with a flat shoulder to be riveted to the dial plate. The other end has a pivot and flat shoulder to which the top plate can be pinned or screwed. When pinned, the pivot protrudes, its end is rounded and a small hole is drilled through level with the top plate. When screwed, the pivot is cut off below the surface of the top plate, leaving enough to accurately locate the plate, and it is drilled with a blind hole and tapped. In this case the screws can be set above or countersunk into the plate. The early American movements often have two of the screws running into pillars also holding the barrel bridge.

- (e) Dial: Dials were purchased and were attached to the pillar plate by pins running through the three feet. Because the plates may vary in thickness, these holes cannot be predrilled.

The Train

The train consists of a barrel, three brass wheels, a steel escape-wheel, the lever and the balance, together with their arbors and pinions.

- (a) Teeth cutting: Cutting teeth on the wheels and the barrel is done by a wheel cutting engine. It is essential that the piece is held exactly on center to ensure the teeth will be concentric with the arbor. Wheels could be cut in stacks if a sufficiently accurate and rigid machine was used, but it is unlikely that barrels could be treated this way. The teeth should be epicycloid. However, it is extremely difficult to shape the very small cutters correctly and the teeth were probably good approximations to the correct shape. Note that this is the most common task, there being about 360 individual teeth to be cut.
- (b) The barrel: The barrel must be turned from brass rod, leaving a boss for the arbor bearing when it is hollowed out. A groove for the snap to hold the lid on must be made. The barrel lid can be punched out, but it then requires turning to thin the inside, leaving a boss for the arbor bearing, and to make the snap. In addition, an eccentric hole must be made on the edge of the lid, although this could be punched out by the die that roughed out the cover. No matter how these parts are made, the arbor hole *must* be concentric with the rim.
- (c) Wheels: Wheels can be punched out. Again the arbor hole *must* be concentric with the rim. It is common to attach wheels to their pinions; the end of the pinion is cut down, the hole in the wheel enlarged, and then the wheel pressed on and riveted to what remains of the leaves. This method of attaching the wheel is restricting in that it limits the position of a wheel in the frame to just above or just below the other wheel that meshes with its pinion. Alternatively, the wheel can be riveted to a collet which fits tightly on the arbor. This is less satisfactory because it is possible for the wheel to rotate independently of the arbor. The English lever, pointed tooth, escape wheel can be cut in a wheel cutting engine. The cutter has to be angled and shaped for the task.

- (d) Lever: The lever and pallets, Figure A5, are two separate pieces which can be punched out of steel stock and then finished. (Originally the pallets were filed by hand.²⁸¹) The pallets are aligned with the lever by a common center, the arbor, and one or two pins or screws going through holes drilled in the lever and pallets. In addition, the lever is drilled for the guard pin. The pallets must be slit, using a file or a saw, to take the jewels. After forming, the parts need to be hardened, tempered, ground and polished; the tools and methods of early watchmaking could not shape hardened steel.



Figure A5

- (e) Balance and roller: The balances in the watches we are considering were plain balances made from steel, brass or gold. The basic shape could be punched out, however the top of the rim and spokes are rounded and this rounding cannot be done by a punch or on a lathe. The underneath is left flat, but in Figure A6 (at the top to the left of the arm) the rim has been filed away to poise the balance

The roller in a single roller escapement is simply a disk which can be punched out or turned, and the hole for the balance arbor made and enlarged to a very good friction fit. The hole for the impulse jewel can be drilled and then shaped appropriately with a punch. This means the roller must be hardened, tempered and finished after the basic work has been completed.

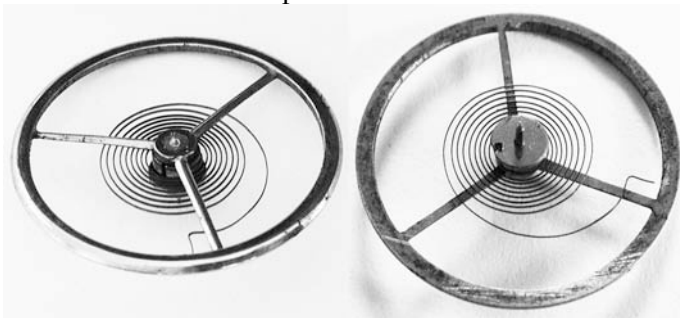


Figure A6

- (f) Arbors and pinions: Except for the barrel, balance and lever, arbors were made from drawn pinion wire. The diameter of the wire and the shape of the leaves formed on it were only approximate and had to be finished.

Making an arbor involves taking a piece of pinion wire and removing the leaves from most of it. Then it is pointed at both ends, mounted in a turn or center lathe, turned to size and the pivots and their shoulders formed.²⁸²

The barrel arbor is turned from steel wire. It then has to be drilled through in the middle to take the hook, which is also made from steel wire, and a square formed on both ends to take a key and the click work.

Both the balance staff and the lever arbor are plain rods with pivots and are turned from steel wire. Both must have extremely accurate diameters so that the balance, roller and lever can be attached by a good friction fit. Note that using plain rods enables the heights of the balance, roller and lever to be adjusted and so overcome variations in the arbors.

- (g) Pivot holes: A major problem with early watchmaking is that it was not possible to turn pivots to specific diameters; neither machines nor hand work could reproduce them to the required accuracy of about 0.01 mm. To overcome this, pivot holes in plates needed to be drilled undersize and then broached out to suit particular arbors. And likewise, balance jewels had to be chosen to suit the balance staff.

Ignoring the balance, all 12 pivot holes have oil sinks. I presume these are milled out after centering the hole.

The Motion-Work

The motion work consists of the canon pinion and the minute and hour wheels.

- (a) Cannon pinion: Although the cannon pinion is also made from pinion wire, it has to be considered separately. It must be drilled through for the post on the center wheel arbor, and then this hole made slightly taper to match the taper on the center wheel post. Finally, the end is cut square for the hand setting key. It is likely that canon pinions were purchased.
- (b) Minute and hour wheels: Minute wheels would be punched out, have their teeth cut and then be mounted on a pinion with a hole for the minute-wheel stud. Hours wheels are the same, except they are riveted to a pipe which would be turned from brass rod.

281 Crossman [1], page 19.

282 Marsh [3], page 53; Berthoud, pages 30-32, 89-91.

Part	Sub part	Screws	Pins	P holes	T holes	Jewels	Arbors	Teeth	Pinion	Note
	Total	26	22	76	26	7	7	360	6	
Top plate	plate									
	case screws	2		2						
	pillar holes			4						
	banking pins		2	2						
	balance cock holes			2	1					
	pivot holes			5						
	oil sinks									
	balance spring stud hole			1						
	potence holes			2	1					
	barrel plate holes			2	2					
Balance cock	balance cock									
	screws	1		1						
	steady pins		2	2						
	jewels					2				buy
	pivot hole			1						
	chatons	3			3					
Balance spring	balance spring									buy
	collet		1	2						
	stud		1	1						
Regulator	regulator			1						buy?
	pins		2	2						
Balance	balance									
	staff						1			
	roller			2		1				
Potence	potence	1	2	1						
	pivot hole			1						
	jewels					2				buy
	chatons	2			2					
Barrel bridge	plate	2		3	3					
	barrel dust guard	3		1						
	steady pins		2	2						
Pillar plate	plate									
	pillars	4		4	4					
	minute wheel stud		1	1						
	case screws				2					
	pivot holes			4						
	oil sinks									
	barrel cock holes				2					
	center wheel sink									
	holes for train bridge			2	2					
	barrel click holes				1					
	barrel click spring holes			1	1					
	motion-work sink									
	dial feet holes			3						
Barrel click		1		1						
Click spring		1	1	2						
Train bridge	bridge	2		2						
	steady pins		2	2						
	pivot holes			2						
	oil sinks									

Part	Sub part	Screws	Pins	P holes	T holes	Jewels	Arbors	Teeth	Pinion	Note
Barrel cock	cock									
	screws	2		2						
	pivot hole			1						
Barrel	barrel		1	1				60		
	arbor		1	1			1			square
	lid			1						notch
	mainspring									buy
Center wheel	wheel							64		
	canon pinion								1	square
	arbor						1		1	
Third wheel	wheel							64		
	arbor						1		1	
Fourth wheel	wheel							45		
	arbor						1		1	
Escape wheel	wheel									
	arbor						1	15	1	
lever	lever		1	3						
	pallets	2		1	2	2				slots
	arbor						1			
Minute wheel								40	1	
Hour wheel								36		pipe
Barrel ratchet								36		square
Dial			3	3						buy

Appendix B: The Endshake Tool

The following description is taken from Jacques David²⁸³; the text in brackets are my insertions. The tool is also described by Sherwood and Watkins.²⁸⁴ Sherwood's explanation is obscure and inadequate, partly because it is described in the context of repair. David's description shows that its primary use was for manufacture, the repetitive processing of batches of watches after the tool had been set up with a standard arbor. Unfortunately, Sherwood does not mention how or when he invented this tool.

The mobile pivots do not have exactly the same length, either because of turning or as a result of polishing. *[Elsewhere David points out that considerable care was taken to ensure that the overall length of arbors was constant. The variations in pivot length result from variations in their shoulders.]* These errors are rectified in the following way, by an operation as delicate as it is ingenious.

The chatons of the top plate are set up and the top plate is mounted on the pillar plate.

The difference between pivot lengths is allowed for by the chaton of the pillar plate. A shoulder is turned on it in order to insert it further into the plate if the mobile pivots are short and to insert it less if the mobile it must receive has long pivots. To be turned in this way, the chaton is gripped in a chuck to the left of the slide rest *[shown in Figure B2]*.

A is the left edge of the graver which turns the shoulder of the chaton. **B** is a center which rests against the jewel. The distance between **A** and **B** varies according to the lengths of the mobile's pivots. The movement is placed between the centers **e** and **g**, with the top plate resting against **g**. The center **f** rests against the flat face of the top plate jewel; for that to happen **f** passes through the hole in the pillar plate.

In the same way the center **e** rests on the shoulder made for the chaton in the pillar plate hole. Thus the distance between the ends of **e** and **f** is the distance of the planting of the 2 jewels.

If a correctly pivoted (standard) mobile is put between **c** and **d**, the position of the graver can be adjusted with respect to the point **B** in such a way that the graver **A** finds the edge of the chaton slightly higher than the jewel *[as indicated in Figure B1]*. The difference between **m** and **n** will give end play to the mobile.

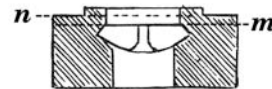


Figure B1 (Reproduced from David, page 62)

This first adjustment of the relative positions of **A** and **B** being done, it should be understood that if a mobile is introduced which has long pivots, the point **B** will overlap the graver **A** and the shoulder turning will be shallower than with the correctly pivoted mobile. This chaton when put in place will descend into the hole less than the normal chaton.

If, on the contrary, a mobile is introduced which has pivots shorter than the standard, the point **B** will be held behind the graver and the graver will remove more material from the chaton. The chaton, when set up in the plate, will descend further than the normal chaton and the mobile will not have too much end play, even though its pivots are too short. The shoulders of all the chatons which go in the pillar plate are turned in this manner.

If there are no jewels, which happens in ordinary movements, end play is given by placing the wheels and testing them. The plate is recessed more or less to suit, using a hand-held or preferably a fixed graver.

²⁸³ David, pages 62-63.

²⁸⁴ Sherwood, pages 85-91; Watkins [2], pages 298-299.

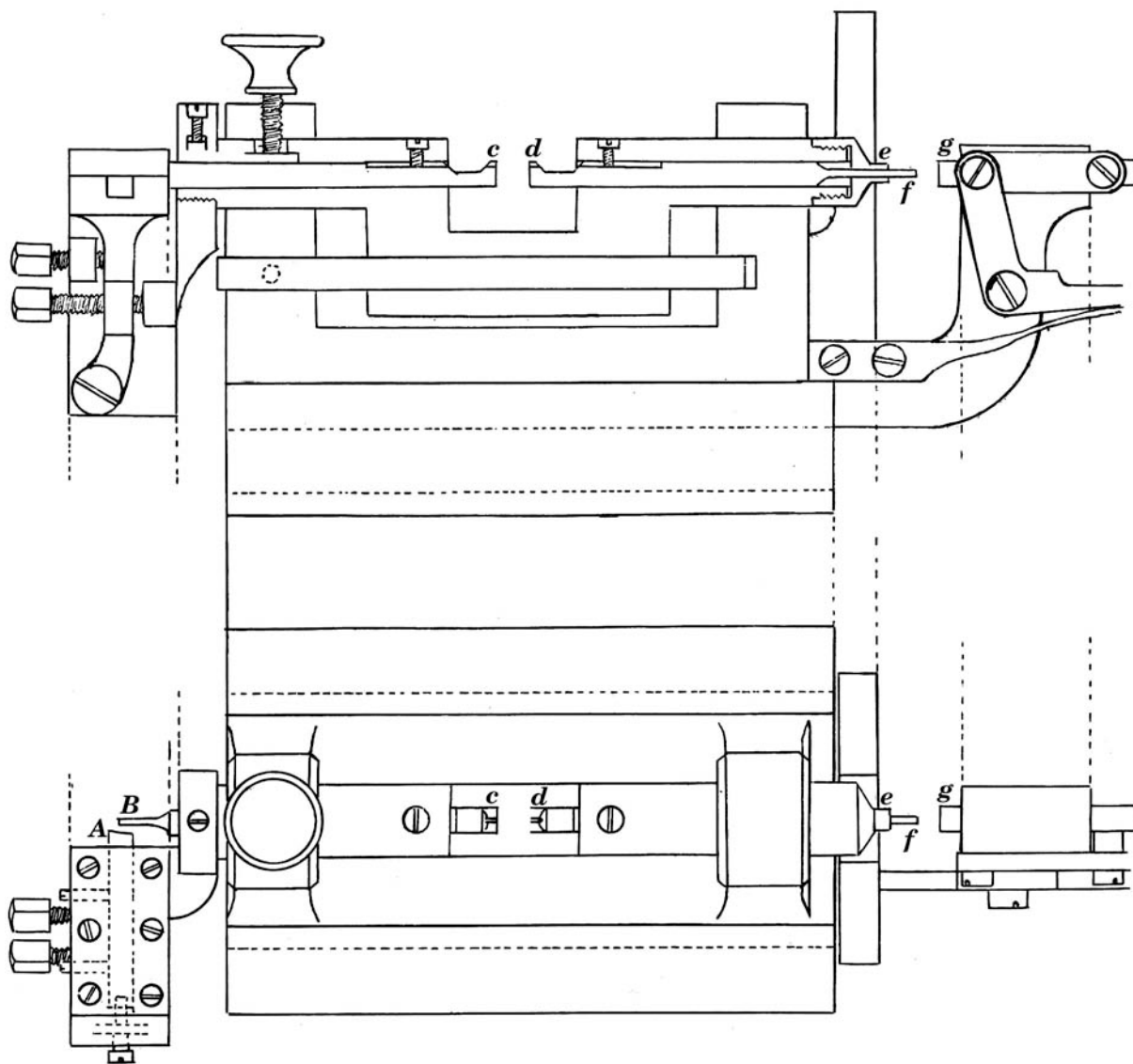


Figure B2 (Reproduced from David, page 63)

Appendix C: Boston Watch Company Production 1850-1856

Assumptions

Because of the lack of data, it is impossible to determine the precise rates of production during the seven years 1850 to 1856 inclusive and the three months, January, February and March 1857, before the bankruptcy. However, it is possible to examine *likely* rates by making some simplifying assumptions.

- (a) *Zero* watches were produced in the first 3 years, 1850 to 1852 inclusive, even though we can be sure some watches were partially completed. Stratton, who designed the first 30-hour watch, joined the company in March 1852.²⁸⁵ About a year later (around March 1853) watches were completed.²⁸⁶ And so there were about 9 months production of watches in 1852, although none were finished because they could not be gilded.²⁸⁷ That is, up to 575 watches could have been made in 1852 (assuming 50 workers, 230 days at 20 man-days per watch), but a lower figure would be more realistic.
- (b) 4,800 watches were completed in the four years 1853 to March 1857 inclusive. Ignoring the 8-day watches and the special movement number 5000, at most 4,980 could have been manufactured, although Price notes that some of the last 100 may not have been made.²⁸⁸ But we know that there were unfinished watches at the time of the bankruptcy and so these only contribute *partially* to the total. Price states that Howard “completed 500 watches”,²⁸⁹ and that 120 were completed by Robbins in Waltham.²⁹⁰ Thus, 180 watches is a very modest allowance for the work done in 1852 and for the watches finished after the bankruptcy. A more realistic figure would be around 4,600.

The purpose of these assumptions is to *maximise* production in the period 1853 to 1856 inclusive and, as a consequence, *minimise* the number of man-days per watch.

The choice of March 1857 as the end date is a consequence of two things.

First, the company was *forced* into bankruptcy against its will, because it had failed to make

mortgage repayments, insurance and tax payments.²⁹¹ That is, all available money had been put into wages and production. The first step towards bankruptcy occurred on 28 February 1857 and so we can be sure the company was running until this date.

Second, the company continued to try to raise capital until it finally filed for insolvency on 15 April 1857.²⁹² As the company was trying to remain solvent up to this date, there is no reason to suppose production ceased until the very last moment.

In addition, Crossman states

*“Within a few days after the sale of the factory at Waltham was under way again with a force of some seventy-five operatives”.*²⁹³

The points I have made confirm Crossman was correct.

- (c) The number of man-days to produce a watch continually *declines*. Assume that with existing machines, tools and methods it takes 18 man-days to make a movement. Then it is inevitable that after this point in time machines, tools and methods either remained the same or improved. And so the number of man-days either remained the same or decreased.

The number of man-days could increase, but only if a different type of watch movement was made. This did not happen; except for some variations in train layout and the number of jewels, all movements were simple timepieces with plain balances and balance-springs, and so there is minimal variation due to adjusting. These were the only watches made by the Boston Watch Company.

- (d) The Waltham Sentinel article is correct and, by March 1856, watches were being produced at the rate of 10 to 12 watches per day by 75 employees.²⁹⁴ Further I will assume this rate was constant throughout the 13 month period March 1856 to March 1857.

The total production is fixed at 4,800. So, as we will see, the problem is to *minimise* production from 1853 to February 1856 inclusive to enable enough watches to be manufactured at a rate of between 6.25 and 7.5 man-days per watch for the remaining period without exceeding the total. This is easier to do if we assume the figure of 10 watches per day at a rate of 7.5 man-days per watch.

285 Abbott [1], page 51.

286 Crossman [1], page 19.

287 Crossman [1], page 18.

288 Price, page 11.

289 Price, page 9.

290 Price, page 11.

291 Price, page 8.

292 Price, page 8.

293 Crossman [1], page 38.

294 Waltham [1], page 144.

- (e) There were 306 working days per year; that is 51 6-day working weeks with 7 holidays. Thus watches were manufactured for 1,224 days, 1853 to 1856 inclusive and for a further 76 days in 1857, making a total of 1,300 days.
- (f) There were 50 employees from 1853 to February 1856 inclusive, and 75 employees thereafter.

Again the aim is to *minimise* production from 1853 to February 1856 inclusive to enable enough watches to be manufactured the remaining period.

Two factors influence the number of employees. First, the company failed primarily because it did not repay its mortgage debts; that is, all borrowed money was put into production. Second, there were no work opportunities for skilled watchmakers outside the watch factory and if they were laid off they would leave the district. Consequently it was imperative that such people be continuously employed. Any reduction in employee numbers would preferably come from laying off unskilled labour, of which there were only a few.

The figure of 50 employees is definitely too low. According to Crossman, in late 1854 the Waltham factory had 100 employees,²⁹⁵ and according to Abbott the number was 90 at that time.²⁹⁶ Marsh does say there were only 50 hands,²⁹⁷ but later he indicates 77 workers (30 watches per week at 18 man-days per watch).²⁹⁸ All four figures may be correct if the workforce varied; initially was probably 50 (mainly transferred from Roxbury), but it built up to around 100 during the first few months at Waltham and then fell.

Realistically there were probably 75 or more workers for an extended period of about 2½ years from mid 1854 to the beginning of 1857. We do not know the number of employees for the first 1½ years, but the lowest figure of 50 is taken to be conservative.

- (g) The number of man-days to make a watch was initially 18 and then dropped or remained static. This figure is unknown, however it cannot be greater than about 25, the time to make a movement entirely by hand. Also, it cannot be too low because, as we will see, a low figure is impossible. According to Crossman, in late 1854,

“the company were struggling to make ten watches per day, but it was more frequently that six only were produced ... [and] very often at the end of the month it was found that not more

*than one hundred [watches] had been completed and put on the market”.*²⁹⁹

And Abbott states production was 5 watches per day with 90 workers.³⁰⁰ Crossman's figures give rates of 10, 16.6 and 25 man-days per watch, and Abbott's figure gives 18 man-days. Marsh also gives the figure of 18 man-days for late 1854.³⁰¹ The lowest rate will be ignored for the moment, and so an initial figure of 18 man-days per watch in 1853 is reasonable.

By far the greatest expense in making a watch was labour. To be more precise, if a watch takes x man-days to make with $x - 1$ days at \$1 per day, and one day of skilled labour at \$2 per day, then the labour cost c is:

$$c = (x - 1) + 2$$

or \$19 for 18 man-days.

Estimating materials at \$4,³⁰² the total cost of production is \$23.

In contrast Crossman indicates that about 1853

*“movements cased in silver cost the company \$18.00 for the work and material”.*³⁰³

This suggests a rate of about 12.5 man-days per watch at that time but, as we will see, such a low rate makes it impossible to have a better rate in March 1856.

Note that the cost of manufacture can only be reduced significantly by reducing the number of man-days of work.

We also have good estimates for the sale price. In 1853 watches “were sold at \$40”³⁰⁴ and in 1856 watches were “worth in silver cases from 30 to 50 dollars each”.³⁰⁵ This is a mark-up of about 73% for 18 man-days per watch and 122% for 12.5 man-days; the former is feasible, but the latter is too high. (In today's money the sale price would be about \$986.³⁰⁶)

Again, the choice of 18 man-days helps to minimise early production to try to enable sufficient later production to fit the Waltham Sentinal article.

Basic Model And Averages

Let d be the day (1 to 1300) and $w(d)$ the number of watches manufactured on day d .

Then the total production is:

$$p = \sum w(d), \quad d = 1, D, \text{ where } D = 1300.$$

Let $m(d)$ be the number of man-days per watch and $e(d)$ the number of employees on day d .

Then:

$$w(d) = e(d) / m(d)$$

299 Crossman [1], page 24.

300 Abbott [1], page 19.

301 Marsh [1], page 11.

302 Harrold [1], page 596.

303 Crossman [1], page 21.

304 Abbott [1], page 18; Abbott [2], page 17; Marsh [1], page 7

305 Waltham [1], page 144.

306 Inflation.

295 Crossman [1], page 24.

296 Abbott [1], page 19.

297 Marsh [2], page 4.

298 Marsh [1], page 11.

Even if the figure of 7.5 man-days per watch is wrong, we must assume that the rate of production improved throughout the 4 years; that is, $m(d+1) \leq m(d)$; the number of man-days to make a watch continually declined, although we don't know precisely how. Consequently, although there may have been some down-turns in production due to decreased numbers of employees, the *general* trend would be that $w(d+1) \geq w(d)$.

Thus the problem can be stated as:

What functions $w(d)$ satisfy the conditions:

$$4800 = \sum w(d), d = 1, 1300;$$

$$7.5 \leq m(d) \leq 18 \text{ for all } d;$$

$$m(d+1) \leq m(d) \text{ for all } d.$$

In addition, if $e(d) \leq 75$ then $0 < w(d) \leq 10$ for all d .

Unfortunately, such loose conditions can be satisfied by any number of functions.

We do know that $p = 4800$ and so the average rate of production was 3.69 watches per day. This very low average has an important implication: The *entire* production of the Boston Watch Company could have been done at 18 man-days per watch using 66 workers. Further, if there was a substantial improvement to the number of man-days per watch for a reasonable period of time, then the average number of workers *must* be much lower.

Step Function Model

This model, Figure C1, assumes there were initially 50 employees and this number remained constant throughout the period 1853 to February 1856, after which there were 75 employees; the number of employees is shown in parentheses.

In this model, $p = w_1 D_1 + w_2 D_2$ where D_1 and D_2 are the number of days for which the rates w_1 and w_2 apply; that is, $D_1 = d_1$ and $D_2 = D - d_1$.

We want to find D_2 , the number of days for which watches were manufactured at the faster rate and, consequently, when this change occurred. From the above, $d_1 = D - D_2$ and so

$$p = w_1(D - D_2) + w_2 D_2 = D w_1 + D_2(w_2 - w_1)$$

and so

$$D_2 = (p - w_1 D) / (w_2 - w_1)$$

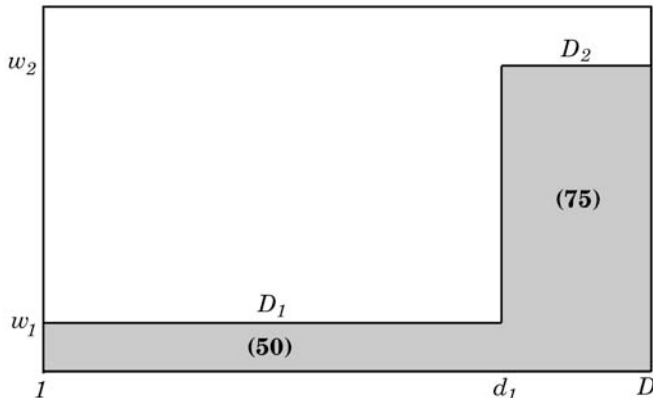


Figure C1

Assume $w_1 = 2.8$ (50 employees at 18 man-days per watch); $w_2 = 10$ (from the Waltham Sentinal Article); $D = 1300$; and $p = 4800$. Then

$$D_2 = (4800 - 3640) / (10 - 2.8) = 161 \text{ days}$$

or $6\frac{1}{3}$ months.

That is, for about $3\frac{3}{4}$ years 3,190 watches were manufactured at the rate of 2.8 per day and then a further 1,610 watches at 10 per day for the remaining $6\frac{1}{3}$ months, from the middle of September 1856. Most important is that the Waltham Sentinal article suggests the rate of 10 watches per day occurred for 13 months, March 1856 to March 1857, which is much too long a period.

Another approach is to accept the beginning of March as the date and find out what rate of production w_1 fits it:

$$w_1 = (p - w_2 D_2) / (D - D_2)$$

That is, for $D = 1300$ days and $D_2 = 331$ days we have $w_1 = 1.54$ watches per day and, with 50 workers, 32.5 man-days per watch. This is impossible.

Alternatively, we can calculate w_2 assuming the other values, and we get $w_2 = 1.61$ and, with 75 workers, 46.6 man-days, which is even worse.

Note that D_2 decreases as w_1 increases. The extreme is when $D_2 = 0$, and then $p = w_1 D$ and w_1 is 3.69 watches per day, as above and, as noted above, this average production rate corresponds to 66 workers producing watches at about 18 man-days per watch. As a consequence, to achieve the rate of 7.5 man-days per watch there must have been significant periods with the number of employees well below 66.

We can alter this model in two ways:

First, we can assume there was zero production in 1857 and so reduce the number of days to 1,224. In this case $D_2 = 242$ days or $9\frac{1}{2}$ months. This is very close to the Waltham Sentinal article period of 10 months from March to December 1856.

However, this means the entire workforce was dismissed at the end of December and remained in Waltham for over *four months* without any income, until the factory re-opened. This is not credible.

Second, we can retain 1300 days and move the period of high activity back to coincide with the Waltham Sentinal article, Figure C2.

If we simply move the peak back then there are 969 days of production at 18 man-days per watch with 50 workers (2,713 watches), followed by 161 days at 7.5 man-days per watch with 75 workers (1,610 watches), followed by 170 days at 7.5 man-days per watch in which 477 watches were made. So the number of workers in this last period is 21. That is, 54 workers were dismissed and remained in Waltham for over *seven months* without any income, until the factory re-opened. This is even less credible.

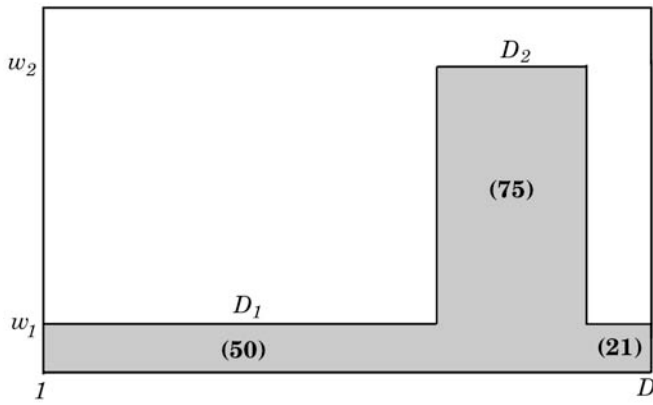


Figure C2

In addition to producing values which are not feasible, this step function cannot be possible. The development of machinery and skills, and hence the reduction in the number of man-days to make a watch probably does occur in steps, each step representing the introduction of a new, labour-saving machine or tool. However, to achieve the very large change from 18 to 7.5 man-days per watch the progress from 1854 to 1857 must have consisted of a number of smaller, incremental changes, and not just one dramatic improvement. That is, if the number of employees was fairly constant, then there would be a regular increase the watches produced each day.

Linear Model

The second model, Figure C3, is much more realistic, because it recognises the fact that the improvement in production must occur incrementally throughout the entire 4 years.

Implicit in this model is that there were no rapid changes in the number of employees, because that would produce a step as in the first model. So it is assumed that initially there were 50 employees and that number grew slowly to 75.

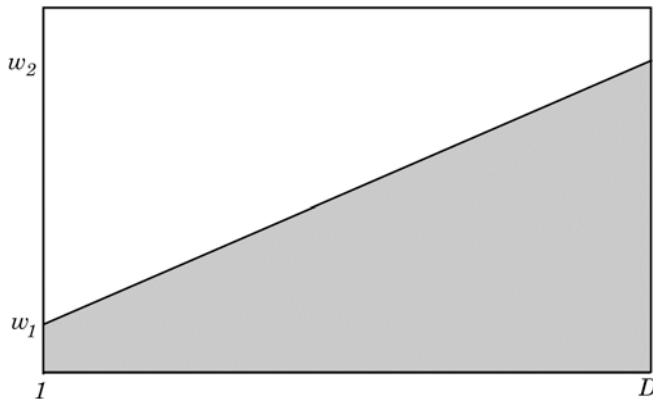


Figure C3

As noted above, the curve should be a series of steps, corresponding to the application of new machines and tools, and to changes in watch design. Further, these steps need not lie on a straight line, as indicated in Figure C3, but may follow any suitable curve.

In the linear model we have:

$$p = w_1 D + \frac{1}{2}(w_2 - w_1)D$$

In this case everything is known except w_1 , so:

$$p = w_1 D - \frac{1}{2}w_1 D + \frac{1}{2}w_2 D = \frac{1}{2}w_1 D + \frac{1}{2}w_2 D$$

and so

$$w_1 = (2p - w_2 D) / D$$

Using the above figures:

$$w_1 = (9600 - 13000) / 1300 = -2.62$$

which is negative and so impossible, the smallest rate per day being zero watches.

An alternative approach is to assume $w_1 = 2.8$, as above, and calculate p , which yields $p = 8,300$ watches, which is 3,500 too high.

In order to get a sensible result we must change w_2 :

$$w_2 = (2p - w_1 D) / D = (9600 - 3640) / 1300$$

which is 4.58 watches per day.

Consequently, this model can only work if the Waltham Sentinal article is wrong and the actual rate of production in March 1857 was 4.58 watches per day or a rate of 16.38 man-days per watch.

Assuming there was zero production in 1857 and so reducing the number of days to 1,224 gives 5.04 watches per day or a rate of 14.9 man-days per watch; this is still unacceptable.

Mixed Model

The above model does not agree with the Waltham Sentinal article because the rate of production does not reach w_2 until the *end* of the period. A better model, Figure C4, is one where production for 255 days from the beginning of March 1856 is static at 10 watches per day. However, it is obvious that this model is worse than the linear model, the area under the curve being greater.

In this case, total production is:

$$p = w_1 d_1 + \frac{1}{2}(w_2 - w_1)d_1 + w_2 D_2 \text{ where } D_2 = 331$$

Using the previous figures yields $p = 9,512$ watches, 4,708 more than actual production.

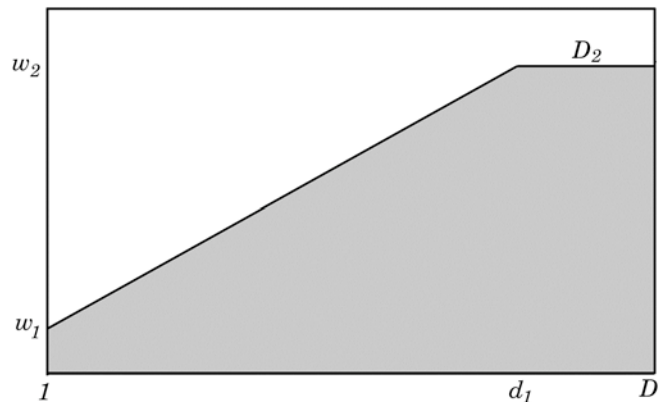


Figure C4

Alternatively we can calculate the value of w_2 that agrees with production:

$$w_2 = (p - \frac{1}{2}w_1 d_1) / (\frac{1}{2}d_1 + D_2)$$

which, for $p = 4800$ gives $w_2 = 4.22$ watches per day or 17.77 man-days per watch.

That is, the rate of production stayed roughly constant at about 17 man-days per watch throughout the entire period 1853 to 1856 inclusive.

Finally, we can calculate D_2 , the number of days of production at 10 watches per day, but we get *minus* 140 days!

Again, reducing the days to 1,224 has no significant effect. That is, the model is impossible.

Other Curves

In order for the Waltham Sentinal figure of 10 watches per day, at a rate of 7.5 man-days per watch, to be credible we need a different curve, and hence a different rate of production at all times other than March 1856.

First, if production for March to December 1856 was 10 watches per day, then the *average* production before that date is:

p_2 (production for 255 days from March on) = 2,550 watches.

p_1 (production for 969 days before March) = $4800 - 2550 = 2,250$ watches.

This is an average rate of 2.32 watches per day which is *less* than the assumed value of $w_1 = 2.8$.

That is, the curve for the first 969 days must approximate that in Figure C1 with production hovering below 2.32 watches per day for most of the time. Certainly it cannot go much above this figure for an extended period of time, because there would need to be corresponding periods zero or even negative production to maintain the average.

Including 1857 produces an average rate of 1.80 watches per day which is much worse.

The only alternative is to achieve such an average by reducing the number of employees in proportion to the number of man-days needed to make a watch. That is, referring to the basic model:

$$w(d) = e(d) / m(d)$$

And so:

$$e(d) = 2.32 m(d)$$

Initially I suggested $m(1) = 18$ and so there would be 42 employees. In March 1856, when 75 people were producing 10 watches per day, the rate must have been 7.5 man-days per watch. If we are to have a sensible evolution of production improvement, this means that the rate of production must have been close to 7.5 man-days per watch just before March. So, in order to keep production down to about 2.32 watches per day, there should have been only 17 employees in February 1856. Because we can be confident that the man-days per watch, $m(d)$, continuously declined, a satisfactory explanation is only possible if employment varied approximately as in Figure C5.

This is not credible. It is clear that throughout 1853-57 Dennison used every bit of available money to keep the factory producing, and so keep employment levels up. Further, Crossman and Abbott put the

employment at 90 to 100 in at least part of 1854, which is impossible for this model.

A variety of other possibilities exist. One is if there was only a small peak of a few days when production was at 10 watches per day; which might happen if employment dropped sharply in or soon after March 1856. It is left to the reader to consider these, but I believe all fail to fit historical facts and so all are impossible.

Conclusions

First, the only sensible conclusion to be drawn is that the Boston Watch Company never achieved a production of 10 watches per day. Indeed, it is most likely that production peaked at about 4.5 watches per day at a rate of about 16.5 man-days per watch.

Second, as production commenced at around 18 man-days per watch, the basic method of manufacturing watches did not change significantly, and the marginal improvement of about 1.5 man-days per watch would be due to minor changes in production methods or watch design.

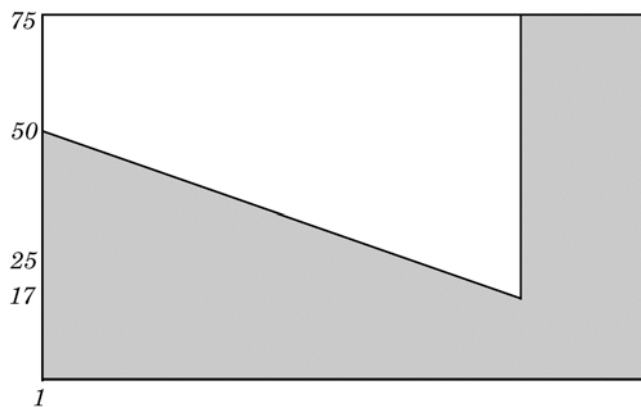


Figure C5

Batch Processing

It remains to explain the figures in the Waltham Sentinal article and Crossman. As noted above, Crossman gives three figures for production in late 1854 of 10, 16.6 and 25 man-days per watch. And the Waltham Sentinal article indicates a rate of 7.5 man-days per watch. How do we reconcile these figures with the above assessment, that rates of production of 7.5 or 10 man-days per watch could never have been achieved?

This apparent contradiction is, in fact quite easy to explain. Over extended periods of time average values are probably valid. However they need not apply to short periods because watches were produced in *batches*.

Although much later, Fitch provides a good description of batching:

"The custom generally prevails of starting watches in large lots, say 1,000 of one kind or grade, 1,000 of another grade being started when these are out of the way, and so on. But

*the watches are not finished in the same order, the partly-finished portions being kept in store and given out in job lots of ten for assembling. ... Thus, while one lot of a thousand watches remains in the works, many subsequent lots may be completed. It is stated at some factories that the usual average time of completion is about five months, including the testing; it being obvious that no such time is required in the simple fabrication of the movement".*³⁰⁷

(This was written in 1880 when the rate of production was about 2.5 man-days per watch. That is watches spent on average about 148 days in store!)

As a simple example, assume watches are made in batches of 100 at a rate of 16 man-days per watch. That is, the time needed to complete a batch would be 1,600 man-days. If there were 60 employees then the batch would take about 26.5 days to finish, assuming there was no other work to undertake. Now assume the watches pass through 4 steps of 4 man-days, each step employing 15 people and each step completed before the next step begins. Then:

- (a) Step 1 takes 400 man-days or 26.5 days, after which the 15 people start on another batch.
- (b) Step 2 takes 26.5 days and the batch is passed on to step 3 after 53 days.
- (c) Step 3 takes 26.5 days and the batch is passed on to step 4 after 79.5 days.
- (d) Step 4 takes 26.5 days during which time all 100 watches are finished.

Thus, the first watch is completed 83.5 days after work started (79.5 + 4 days) and the last after 106 days.

The total amount of work is 1,600 man-days. But, production (output of completed watches) is *zero* for 83.5 days and the 100 watches are completed in 22.5 days at a rate of 2.25 man-days per watch; that is, the apparent production in this period is about 4.5 watches per day when the overall production rate (100 watches in 106 days) is only 0.94 watches per day.

Of course, as Fitch states, batches overlap. The above suggests the people performing step 1 work for 26.5 days and then are idle for 79.5 days, which is ludicrous. It also assumes each group of 15 people cannot perform other tasks. If, for example, all of the workers who performed step 3 were transferred to performing step 4 then the last phase would take 30 people only half the time, 11.25 days, at a rate of 8.9 watches per day.

Although this example is artificial, it indicates that *significant* rate variations can occur for short periods of time, and that apparently very high or very low rates of production are possible compared to the overall average rate; which is why Crossman could cite three very different figures.³⁰⁸ It is only when production is examined over a longer period of time that representative figures can be determined.

Thus the high figures cited by the Waltham Sentinel article and Crossman need not conflict with the above analysis of long-term production.

307 Fitch, page 677.

308 Crossman [1], page 24.

Appendix D: American Watch Company Production 1857-1858

Sources Of Data

In contrast to the production of the Boston Watch company, we have reasonably precise information about the production of the American Watch Company in its first two years. This information comes from the following three sources:

Month-by-month production figures;³⁰⁹ Table D1, column 3. Except for two entries for which the year is uncertain, these figures are exact. Although the possible error caused by the two doubtful figures might noticeably change the November 1858 production, the overall effect is about 1.1% which is not significant. The total production is 9019 watches.

This data only includes *new* production. Although the finishing of Boston Watch Company watches would have occupied employees during the first few months, this has been ignored.

Waltham			
Month	Payroll	Watches	Costs
5/57	823		
6/57	2,110		3000
7/57	2,575	100	3375
8/57	3,728	250	4978
9/57	3,190	150	4140
10/57	417	130	1307
11/57	1,316	470	4016
12/57	2,713	260	3993
1/58	2,552	540	4672
2/58	2,257	550	4957
3/58	3,499	690	6754
4/58	2,817	720	6197
5/58	3,570	700	6870
6/58	6,171	720	6465
7/58	0	710	6425
8/58	3,183	590	6043
9/58	3,506	600	6406
10/58	3,500	510	5789
11/58	3,500	600	6149
12/58	3,500	729	6665

Table D1

Month-by-month payroll figures; Table D1, column 2.³¹⁰ The monthly payroll figure and the corresponding production are used in a spreadsheet to determine the man-days per watch and to generate the graphs. For convenience, the spreadsheet uses figures representing the payroll for full-time workers for full months. As a consequence, when there is part of a month or part-time work, I calculate figures for the *equivalent* full-time complete month activity. (It is impossible to allow for variations of the work-force within a month because such detail is not known.)

Moore's provides payroll data starting in July 1857 and ending in September 1858, and so the figures for

June 1857 and October to December 1858 are estimates. The \$2,110 estimate for June 1857 is simply the average of the May and July figures. The October to December figures should correspond to full production as, except for the months discussed below, Robbins kept manufacturing as fast as he could. The average of the preceding 7 months is \$3,249, and \$3,500 is a sensible estimate.

There are 5 extraordinary months; May 1857, October 1857, November 1857, June 1858 and July 1858.

May 1857: The payroll for about 15 days, half a month, from the sale on May 9 to May 23, was \$822.90.³¹¹ This corresponds to a monthly payroll of about \$1646. It is this amount that is used to calculate the June 1857 figure.

October 1857: The October 1857 figure of \$417 is because it appears Robbins effectively stopped production for the month. However Crossman notes:

*"the time of the employees was reduced in October to one-half, with half pay and the factory was running this way for a few weeks. Then it was decided that still another reduction must be made ..."*³¹²

Although vague, it appears likely that this reduction occurred for the whole of October 1857 and was immediately followed by a three-week reduction in November.

Being pedantic, let the actual payroll be P , the actual number of workers be w and the average monthly rate of pay be r . Then in October:

$$P = wr/2$$

the workers being on half pay, and so

$$w = 2P/r$$

If the normal hours worked per person in a month is h , then the total labour L done in October was:

$$L = wh/2$$

If w' is the equivalent number of full-time employees who could do the same amount of labour, then

$$w'h = wh/2$$

and

$$w' = w/2$$

The equivalent payroll P' , the payroll for full-time, full-pay to do the same work is

$$P' = w'r = wr/2$$

and as $w = 2P/r$

$$P' = (2P/r)(r/2) = P = \$417$$

309 Waltham [2].

310 Moore, page 315.

311 Moore, page 315.

312 Crossman [1], page 39.

That is, given P and r for October we can determine w , w' and P' ; the values will be considered after we have examined the determination of r , the rate of pay.

November 1857: For 3 weeks in November there was a 50% wage cut,³¹³ and during this time hands worked $\frac{3}{4}$ time.³¹⁴ It is assumed that hands worked full-time on full-pay for the remaining week. Because the spreadsheet uses the equivalent full-time payroll, w' and P' need to be calculated.

Given the above working conditions, the actual payroll is

$$P = \frac{1}{4}wr + \frac{3}{4}wr/2$$

which is one-quarter of the month on full rate and three-quarters of the month on half rate. And so

$$P = \frac{1}{4}wr + \frac{3}{4}wr = \frac{1}{2}wr$$

Therefore

$$w = \frac{2}{3}P/r$$

If the normal hours worked per person in a month is h , then the total labour L done in November was:

$$L = \frac{1}{4}wh + \frac{3}{4}w\frac{3}{4}h$$

That is, one-quarter of the month full-time and three-quarters of the month at three-quarter time. And so

$$L = \frac{1}{4}wh + \frac{3}{4}wh = \frac{13}{16}wh$$

If w' is the equivalent number of full-time employees who could do the same amount of labour, then

$$w'h = \frac{13}{16}wh$$

and so

$$w' = \frac{13}{16}w$$

The equivalent payroll P' , the payroll for full-time, full-pay to do the same work is

$$P' = w'r = \frac{13}{16}wr$$

But $w = \frac{2}{3}P/r$ and so

$$P' = (\frac{13}{16}\frac{2}{3}P/r)r = \frac{13}{12}P = \$1711$$

June and July 1858: The 1858 discrepancies are mysterious. Moore notes that in July there was “No cash available for payroll”, but he does not comment on the extraordinarily high figure for June.

As 710 watches were produced in July there must have been a reasonable number of workers, and it is tempting to say the figure for June is the total wages for both months June and July, and average them. But it is very unlikely that Robbins would pay workers in advance and this explanation does not seem credible.

A second explanation is interesting, but also dubious. Dennison stated that

*“I however remained as Superintendent of the works until 1861, the first year of the war at which period the Director of the Company saw fit to cut down my force from over 200 persons to about 50 and adopted a course to completely demoralize these few so that no results could be obtained and then blame me for the results of their bad management”.*³¹⁵

Although Dennison refers to 1861, Keith does not mention this event and he indicates that there were around 75 to 78 hands at about this time.³¹⁶ But Dennison’s statement fits quite well with the 1858 payroll figures.

If I may fantasize, it is possible that Dennison doubled the work-force without consulting Robbins. When Robbins found out he would have been furious and faced with a wages bill he could not afford. So he paid up and then put everyone off for a month to get his expenses back under control. It is probable that Robbins furloughed his workers. That is, when numbers needed to be reduced they were not dismissed, but were forced to take time off without pay. Furloughing is good for the workers because they are automatically re-employed when business picks up, and so more inclined to stay in Waltham rather than seek permanent work elsewhere.

In the following I have given preference to the production figures and split the June payroll across both June and July, so that the monthly figures used are \$3085.

Month-by-month costs, Table D1, column 4. These are based on Harrold’s data.³¹⁷ The total cost of production T in any month is:

$$\text{payroll} + \$500 + xU$$

where \$500 is a constant allowance for overheads, x is the cost of materials, which is based on \$1 for watch materials and \$3 for the case, and U is the production in that month. However, Harrold takes into account that some movements were sold uncased and so x varies; it is 3 for June 1857 to January 1858 and 4 for the remaining time.

I use the same formula to estimate total costs for the Waltham data because it produces credible figures.

Both Harrold and I determine production cost per watch by simply dividing the total cost of production for a month by the number of watches made in that month, T/U . This is a bit crude and the early figures are erratic, but the later figures, especially cumulative figures, are consistent.

A major component of the overheads is advertising costs. The 1859 annual report includes \$4,559.36 or \$380 per month for advertising.³¹⁸ There may be some doubt about this figure. Robbins also gives \$24,457.53 for the payroll,³¹⁹ but this is much too low, not only because it disagrees with the figures in Table D1, but also because the number of employees would be too low for the number of watches produced; it represents production at the average rate of 2.0 man-days per watch which is not possible. So perhaps the advertising costs are also too low?

313 Moore, page 315.

314 Keith, page 43.

315 Dennison [6], page 2.

316 Keith, page 59.

317 Harrold [1], page 596.

318 Robbins [2], page 2.

319 Robbins [2], page 2.

Just what other “overheads” should be included is a matter of opinion. It is common practice to separate out direct costs of production (cost of sales) from indirect costs (expenses), but Robbins does not do this.³²⁰ Some expenses, such as machinery furniture and buildings, have to be averaged over the life of the item. Also, expenses associated with unfinished work cannot be included. Unfortunately Robbins is vague. For example, he states that the “Material goods in progress” to be \$45,000, which is an enormous figure.³²¹ Presumably it is not the *cost* of work in progress but the *potential sales value* of it, in which case it corresponds to about 2,250 partially completed movements, a sensible number.

From this we can estimate the average cost of a watch.

The data published by Harrold will not be considered further, because the production figures, presumably from Hawkins,³²² are clearly too low, the total being 7725 watches including 125 Boston Watch Company movements. However, except for a few instances, it shows the same trends and produces very similar conclusions.

Employment

In order to determine the rate of production (man-days per watch) we need to know the number of employees each month. However, this is not simple, because different workers would have had different rates of pay depending on their different skills. And so some assumptions have to be made.

The number of workers earning particular rates of pay can, in principle, be estimated from Fitch:

*“The percentage of the numbers of persons in the various duties of watch-making is here given roundly in an average of the practice at several factories, viz: The springing and finishing, including train finishing, 17½ per cent.; the pinion roughing and finishing, 15½ per cent.; the screw, flat steel, and escapement work, 12½ per cent.; the jewel making, 7½ per cent.; the jewelery, 7½ per cent.; the plate work and engraving, 7½ per cent.; the balance making, etc., 7 per cent.; the machine-shop work, 6½ per cent.; the dial work, 6 per cent.; the carpenter and blacksmith work, clerical work, watching and time-keeping, 6 per cent.; the stoning and gilding, 3½ per cent.; the mainspring making, 1½ per cent.; the nickel-finishing, 1½ per cent. ... The percentage of female operatives to the whole number ... for the whole work, from 33 to over 40 per cent.”*³²³

Although Fitch was writing in 1880, and there were some changes in the types of watches manufactured

which would alter these percentages, they at least provide a starting point.

It would be too difficult to estimate wages for each group, and so I will assume there were only two *average* rates of pay, one for skilled workers and one for the rest of the employees.

Assume w_1 workers earn on average e_1 (\$ per day) and w_2 earn on average e_2 . So the total daily payroll P is:

$$P = w_1 e_1 + w_2 e_2$$

Assume the fraction of workers earning the lower rate e_1 is p_1 and the fraction of workers earning the higher rate e_2 is p_2 . Then $p_1 + p_2 = 1$. That is, if w is the total number of employees then:

$$w_1 = p_1 w, w_2 = p_2 w \text{ and}$$

$$P = p_1 w e_1 + p_2 w e_2$$

and so:

$$w = P / (p_1 e_1 + p_2 e_2)$$

I will assume 17.5% of the workers earn the higher rate e_2 ; that is $p_2 = 0.175$. These are primarily springing and finishing workers from Fitch’s figures, although other classes, such as mechanics probably should be included. So:

$$w = P / (0.825 p_1 + 0.175 p_2)$$

That is, the average rate of pay r is

$$r = 0.825 p_1 + 0.175 p_2$$

The two rates of pay and the percentages can be varied to produce different figures. However there are some constraints:

- (a) It is generally accepted that the Boston Watch Company had about 75 employees at the time of the bankruptcy and that Howard took some (about 15?) with him to Roxbury. We can be confident that Howard took the most skilled workers, those that he could not easily get elsewhere. And so Robbins would have needed to replace these people as quickly as he could.
- (b) Robbins would not want to significantly reduced the work-force when he took over. If he had, many people with hard-to-replace skills would have left the area and so, just as Dennison had to do, it was necessary to maintain the work-force, either by furloughing them or by employing them and suffering a significant payroll without any money coming in.
- (c) Equally, Robbins needed to keep costs as low as possible until new machinery had been made and production of new watches started. Hence he would not have hired any new workers unless they were absolutely essential. From the available data, Robbins had to support the work-force during May and June 1857 before any new work was completed and could be sold. Consequently, the number of employees at the start of the

320 Robbins [2], pages 2-3.

321 Robbins [2], page 2.

322 Hawkins.

323 Fitch, page 678.

period we are considering (May 1857) should not be more than about 60.

- (d) The ratio of highly skilled workers to the rest needs to be roughly constant. If they are not in balance either there would be too few movements available to fully occupy the finishers, or there would be a bottle-neck with excessive movements waiting for finishing. Thus the figure of 17.5%, or another choice, can be used throughout the period being examined.

In the following I calculate the rate of production using three different estimates of the average rate of pay r :

Waltham: These figures are based on $e_1 = \$1$, $e_2 = \$3$ and $p_1 = 0.175$. That is, $r = \$1.40$.

Moore: Moore calculated that in August 1859 124 workers were employed at an average wage of \$1.546.³²⁴ That is, a payroll of about \$192 per day and \$4,888 per month. If we assume there was no change in rates of pay from 1857 to 1859, then $w = P/1.546$ and the resulting work-force is almost exactly the same as that produced by $e_1 = 1.25$, $e_2 = 3$ and $p_2 = 0.175$. That is, $r = \$1.57$.

Harrold: In contrast, Harrold indicates factory wages were \$1 per day and “*trained and skilled employees received about \$1.50 per day*”.³²⁵ Based on these figures, $r = \$1.09$.

Using these three estimates we can calculate the number of employees for each month. With the exception of the special months discussed above, this is straight forward.

For May 1857 the monthly payroll of \$1646 is used in all calculations.

For October 1857 the actual number of workers is double that indicated by the payroll:

Rate of pay	Equiv full-time	Actual
Harrold	15.04	30.08
Waltham	12.11	24.22
Moore	10.58	21.16

October 1857

For November 1857, the actual number of workers is $16/13$ of the equivalent full-time workers:

Rate of pay	Equiv full-time	Actual
Harrold	61.70	75.94
Waltham	49.70	61.17
Moore	43.40	53.42

November 1857

Figure D1 gives the actual number of workers for the three values of r , Waltham data, Moore and Harrold.

The Waltham data and Moore’s data give initial work-forces of 48 and 42 which are lower than we would expect. However, Harrold’s rates of pay produce a correct initial work force of 59, although the August and September numbers are too high.

In October 1857, when Robbins employed very few people, we can assume the workers were put off temporarily with a guarantee of re-employment to ensure they remained in Waltham. The workforce for this month is calculated using the above formula. However, we probably should assume that the workers kept on were the most skilled and were occupied finishing watches. So, based on all earning \$3 per day, the number may have been as low as 11 people.

Note that the August and September 1857 figures seem too high; it is unlikely that Robbins would have employed over 100 people so early.

Production

Figures D2 and D3 show the production and cumulative production of finished watches.

Unit Price

As noted above, Harrold estimated the total cost of production to be *payroll + overheads + materials + case* and I have used his estimates applied to the Waltham production data. Thus the unit price is calculated independently of the number of man-days required to make a watch.

Figure D4 shows these unit costs.

The cost figures for June to December 1857 vary wildly, but after that they settle down to a fairly stable value around \$10. The high early figures result from no or few watches have reached the stage where they could be completed. And so there is a high payroll with few finished products.

A better idea of cost is obtained by using a cumulative average, Figure D5. The graph calculates the unit cost in month M as (*sum of costs for months June 1857 to M*) divided by (*sum of production for months June 1857 to M*). This evens out the monthly variations and gives a better idea of the way unit costs changed. Again the initial figures are too high, demonstrating the fact that production was in full swing but no or few movements were ready for finishing; in particular, about 72 people were employed in June but zero watches were produced!

As a result the July cumulative figure has about 72 people working for 2 months and producing only 100 watches. However, later figures give a good view of production with the final cost being about \$11.

³²⁴ Moore, page 315

³²⁵ Harrold [1], pages 585-586.

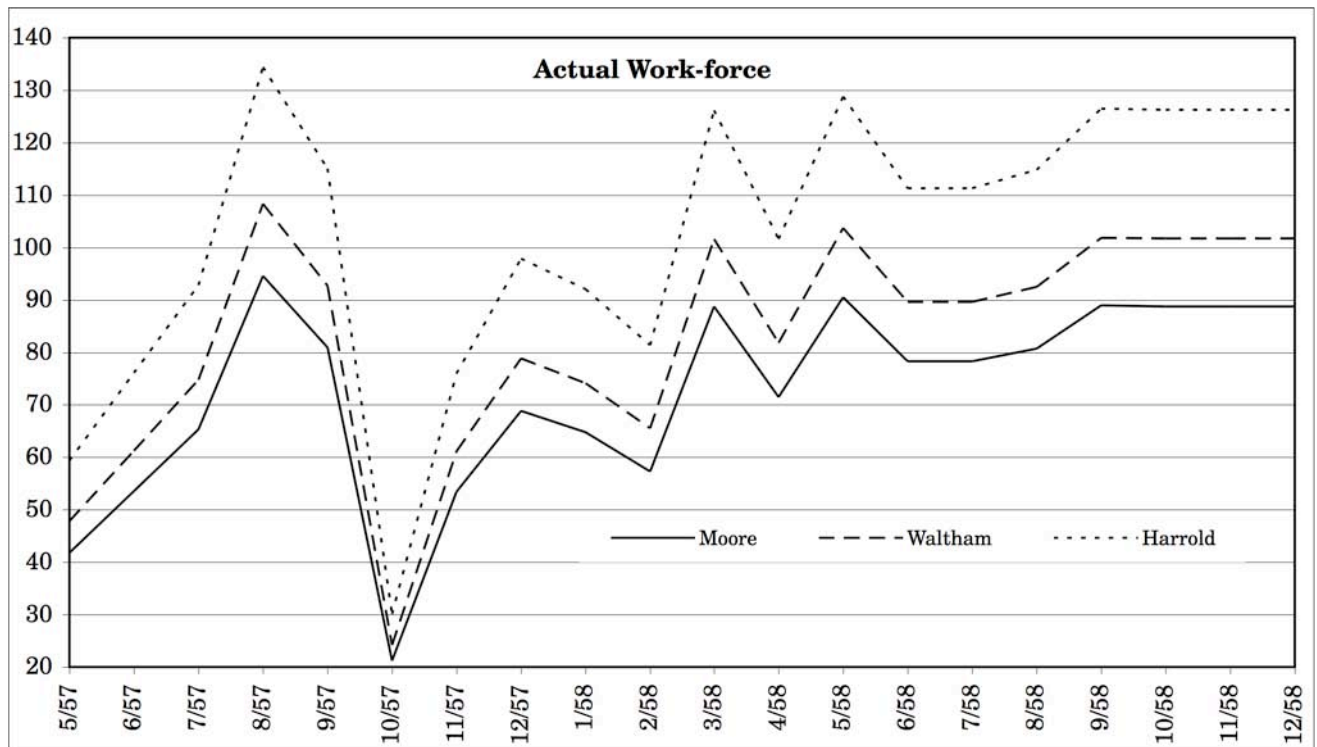


Figure D1

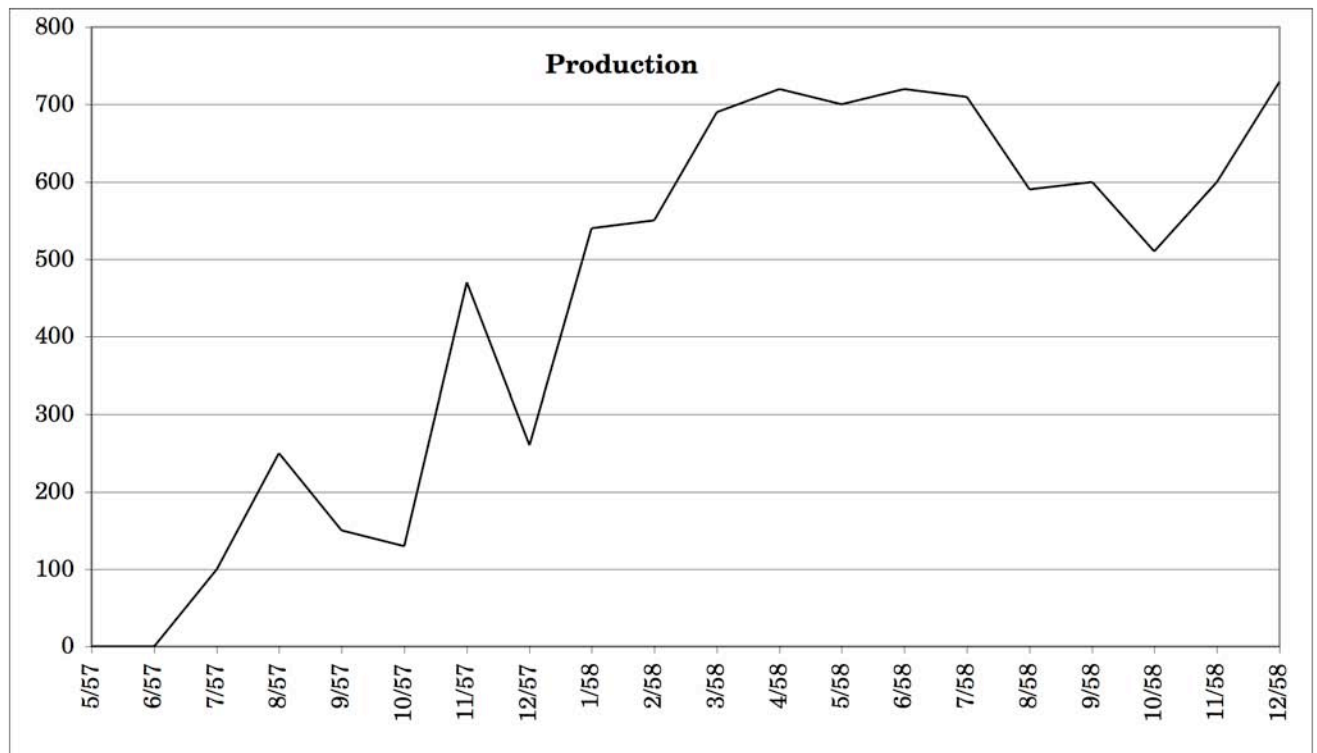


Figure D2

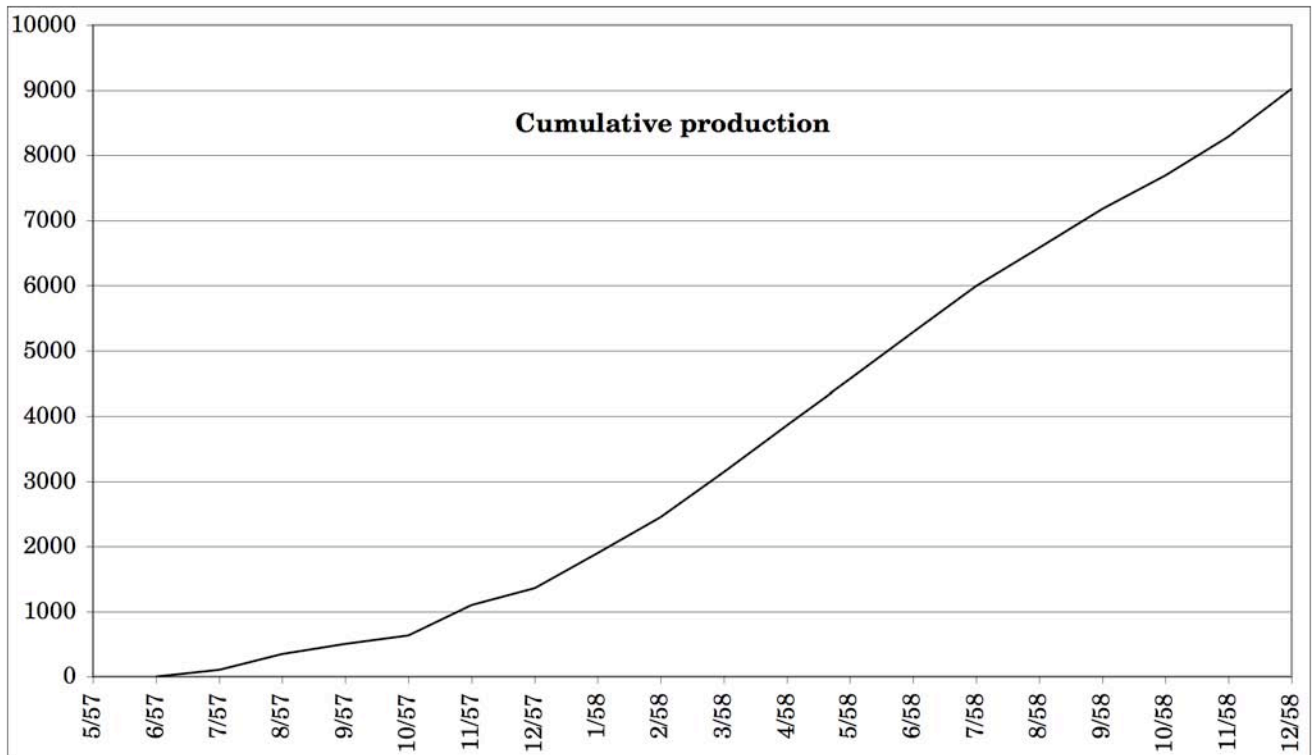


Figure D3

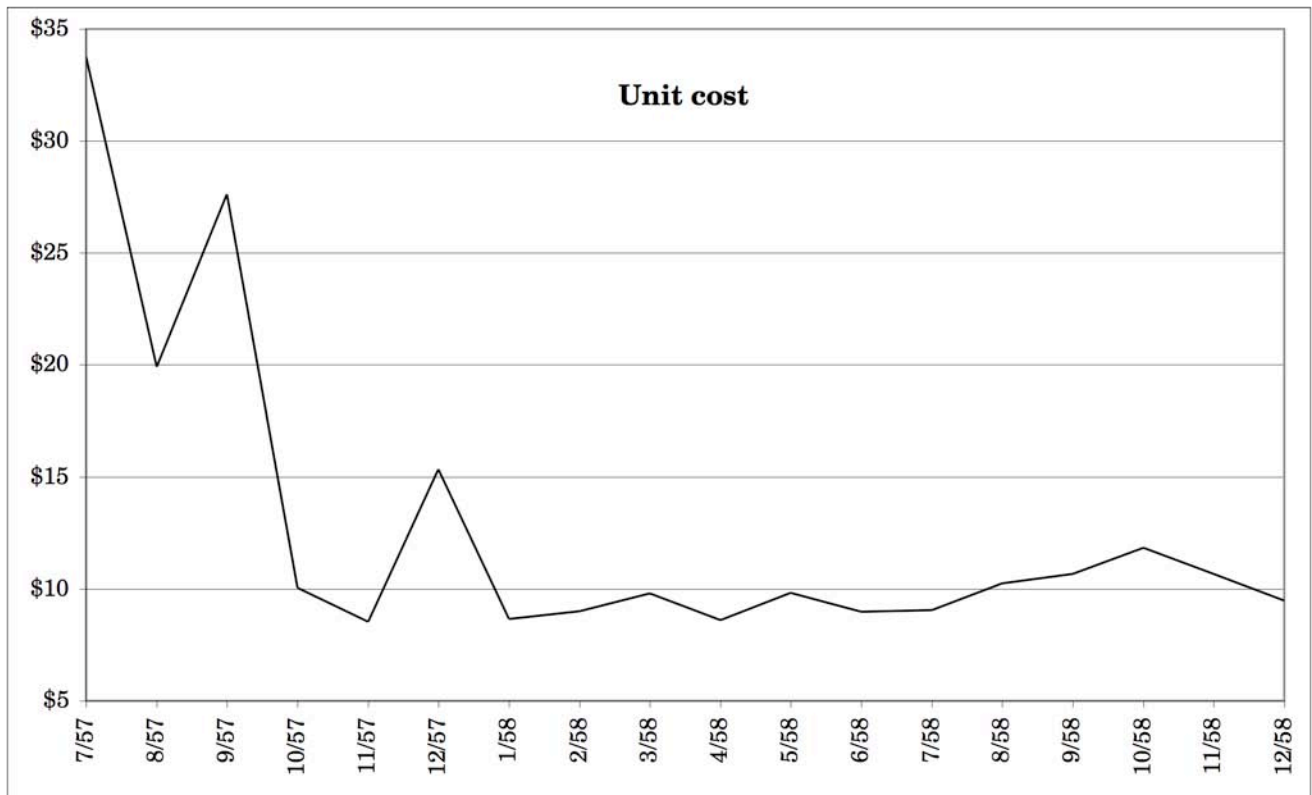


Figure D4

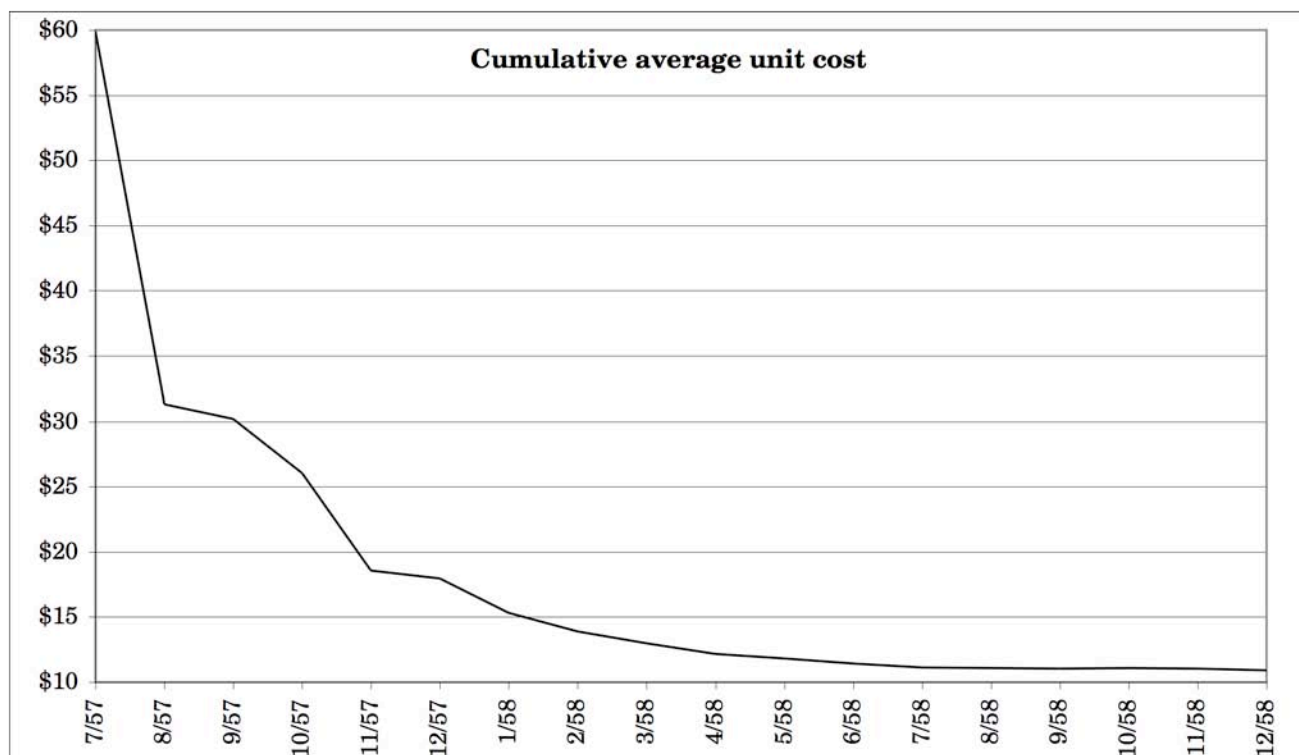


Figure D5

Man-Days Per Watch

Unit price and man-days per watch are closely related. The largest component in manufacture is labour and the only way to significantly reduce the unit price is to reduce the number of man-days.

The number of man-days per watch is based on the estimate of the equivalent full-time workforce. This is the same as the actual work-force except for the special months October and November 1857, which are based on the above tables. I assume a 306 day working year and so the average working days per month is 25.5. From this and the production data we get Figure D6.

Again the starting figures are too high, and the October and November figures are too low.

Although the figures for the first few months are too high, the cumulative average, Figure D7, provides a more realistic picture overall.

What is important is to note that the significant differences in the methods of estimating the rate of pay r make very little difference to the outcome.

According to Moore, in the next year 1859 there were 200 workers producing 50 watches per day, 4 man-days per watch.³²⁶ These figures fit with the above analysis.

If we omit the first 6 months as atypical, the average man-days per watch is 3.76 (Moore), 3.75 (Waltham) and 5.34 (Harrold). Indeed, even in the extreme case where the entire work-force is paid \$1 per day ($p_2 = 1$), the initial work-force is 64 and the rate of production only rises to an average of 5.81 man-days per watch. In fact, if we include all months the figures are 4.03 (Moore), 4.61 (Waltham) and 5.72 (Harrold) respectively, with the extreme case being 6.23 man-days.

These figures are embarrassing. With the Boston Watch Company our problem was to try to *reduce* the number of man-days per watch without reducing the number of employees to an unrealistic level. However, with the American Watch Company the problem is the exact reverse; how can we *increase* the number of man-days per watch without increasing the number of employees. This is because a figure like 3.76 man-days per watch is stretching credibility. Some of the variations in Figure D6 can be explained by batching (discussed at the end of Appendix C); in particular the low values in October and November 1857 followed by a high value in December. But the consistent values from January to December 1858 clearly show normal production at a rate significantly less than 5 man-days per watch.

³²⁶ Moore, page 56,

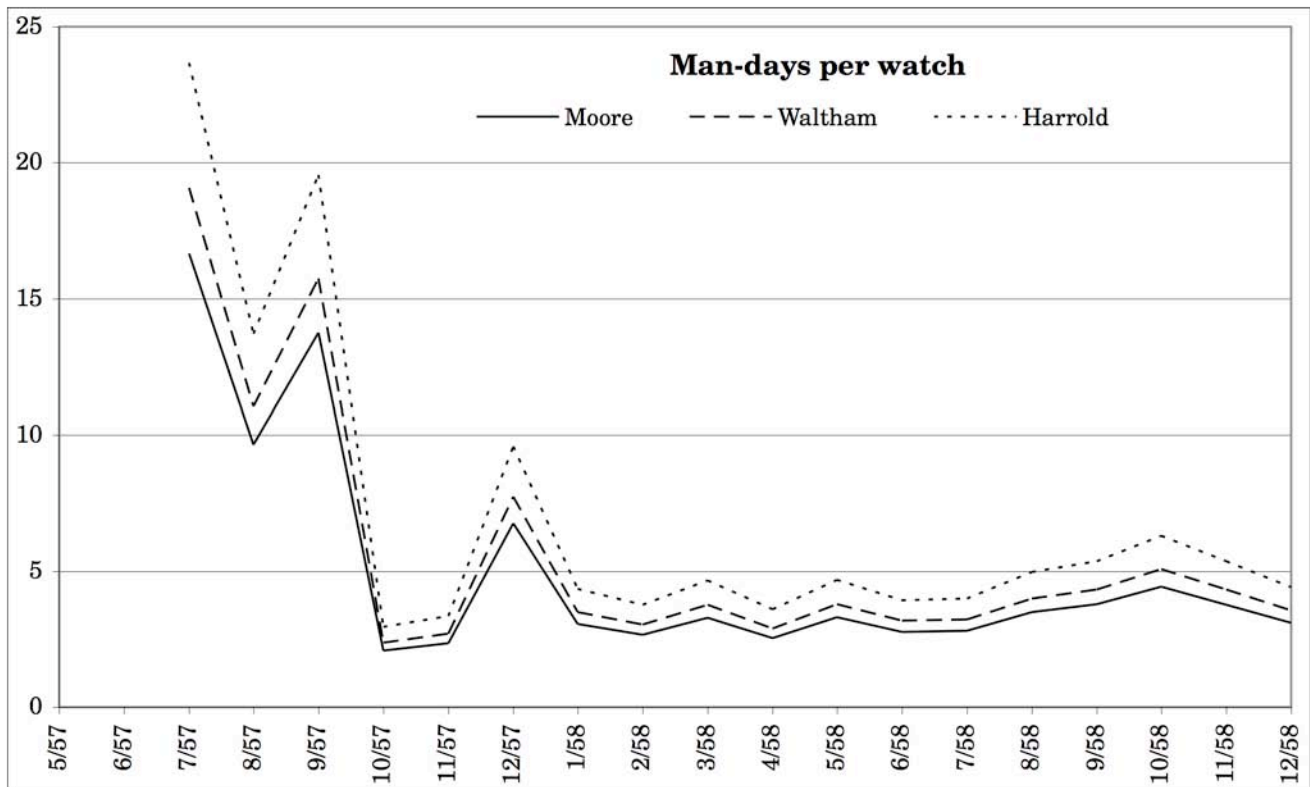


Figure D6

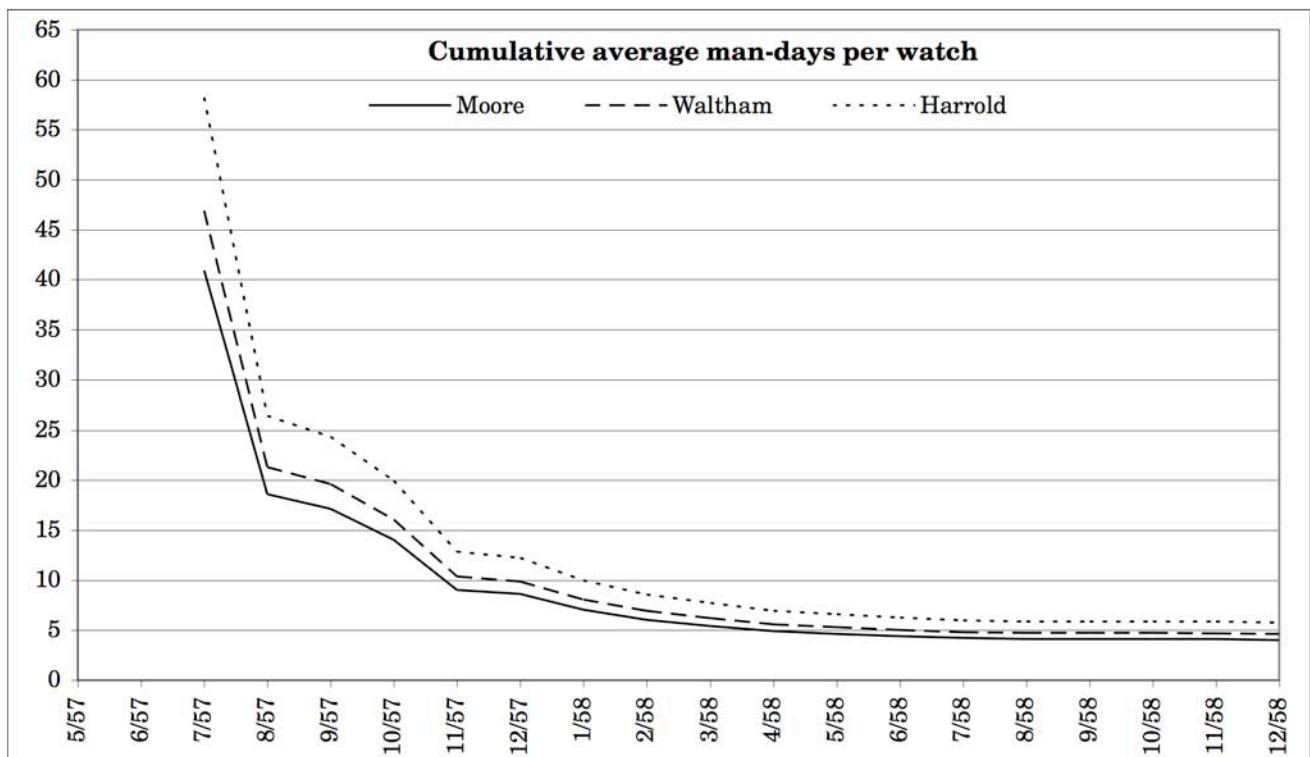


Figure D7

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