Frank George Woollard: forgotten pioneer of flow production

M.L. Emiliani
Central Connecticut State University, New Britain, Connecticut, USA, and
P.J. Seymour
Vicarys of Battle Ltd, Battle, UK

Abstract

Purpose – The purpose of this paper is to introduce management historians to the long-forgotten work of Frank George Woollard (1883-1957), who in the mid-1920s established flow production in the British motor industry, and its remarkable similarity to current-day production principles and practices used by Toyota Motor Corporation, also known as lean production.

Design/methodology/approach – Overview of Frank Woollard's life and work obtained from newly discovered journal papers, his 1954 book, *Principles of Mass and Flow Production*, newly discovered archives, and new first-hand testimony from a close friend and from a long-time family friend.

Findings – Frank Woollard was a pioneer in the establishment of flow production in the British motor industry in the mid-1920s and the principal developer of automatic transfer machinery. His accomplishments are comparable to Taiichi Ohno, regarded as the architect of Toyota's production system.

Research limitations/implications – Woollard's accomplishments in flow production are a fruitful area for future research given the speed and completeness with which flow production was established at Morris Motors Ltd, Engines Branch. Newly discovered papers describing his flow production system have yet to be studied in detail by academics.

Practical implications – Woollard's application of flow production beginning in 1923 means that timelines for discoveries and attributions of key accomplishments in lean management must be reexamined and revised.

Originality/value – Woollard's work fills important gaps in the literature on the history of flow production generally and in the British motor industry in particular. His work constitutes an early application of current-day lean principles and practices, and is therefore noteworthy and relevant to management historians and the operations and production management community. It is hoped that this paper will inspire management historians to study Woollard's work and place him in the context of other early twentieth-century pioneers in industrial management and flow production.

Keywords United Kingdom, Automotive industry, Flow production, Lean production, Economic history

Paper type Research paper

Introduction

> The ideal arrangement for flow production should resemble a watershed; the river being the main assembly track, fed by tributaries in the shape of sub-assembly lines which, in turn, would be supplied by streams representing the machine lines fed by brooks typifying the material conveyors. Each part should flow continuously forward. There should be few bends, no eddies, no dams, no storms, no freezing should impede the inevitable flow to estuarine waters – the dealers – and ultimately to the sea – the customers (Woollard, 1954b, p. 48).

Frank George Woollard (1883-1957, Plate 1) is a man that few management historians or current-day management practitioners have ever heard of. He was the General Manager of Morris Engines Ltd, Coventry, a member of the Morris group of companies, makers of

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Source: Wood (1998)

Plate 1.
Frank George Woollard, *circa* 1928

the famous Morris Motor cars (Jarman and Barraclough, 1965, 1976; Edwards, 1983). He became a Director of Morris Motors Ltd and was a principal participant in the development of the British motor industry between 1910 and 1931. The reasons for Woollard having fallen into obscurity are not entirely clear. He wrote numerous papers in the mid-1920s describing his pioneering flow production methods, and most were published in international journals that general managers and production engineers, especially those in the emerging global automotive industry, would have likely read. His accomplishments in the fields of flow production, industrial automation, and progressive management, aided by strong support from his boss William Richard Morris (ennobled as Lord Nuffield in 1934 (Andrews and Brunner, 1955)), are as impressive as other great industrial pioneers (Williams *et al.*, 1994).

One of Woollard's distinctive contributions was to prove that achieving flow for engineered goods in low volume production (compared to Ford in the USA) resulted in costs that were as low or lower than that which could be achieved by large-scale mass production. Thus, a small- or medium-sized automaker producing a few thousand or tens of thousands of automobiles annually could compete against large foreign auto companies that produced much greater volumes of automobiles and who relied on economies of scale to reduce costs (Maxcy and Silberston, 1959). Woollard's work reversed the commonly held view that flow was only useful as a production method when the volume of goods was very large, such as in the production of Ford Model T cars.

The founder of Toyota Motor Corporation, Kiichiro Toyoda (Ohno, 1988; Toyota, 1988), would have these same insights about flow in 1937, some 12 years after Woollard reduced it to practice, but it would be 1955 before Toyota was able to achieve flow in its engine shop (Shimokawa and Fujimoto, 2009, p. 79). In addition, it took the legendary Taiichi Ohno (1912-1990), the principal architect of Toyota Motor Corporation's production system (Ohno, 1988), six years to do what Woollard did in less than two years, and at half the engine volume of Morris – 22,786 engines at Toyota in 1955

(Toyota, 1988, p. 461) compared to 55,582 engines at Morris in 1925 (Andrews and Brunner, 1955, p. 112). Woollard's contribution to progressive manufacturing management practices is substantial and comparable to Mr Ohno's work.

Curiously, reference to Woollard is found mainly in economics and labor relations literature (Maxcy and Silberston, 1959; Lewchuk, 1987; Williams *et al.*, 1994; Foreman-Peck *et al.*, 1995; Tolliday, 1998; Tiratsoo, 2003), as well as in works by historians of the British motor industry (Andrews and Brunner, 1955; Overy, 1976; Wood, 1988; Hounshell, 1995, 2000a, b; Seymour, 1999; Zeitlin, 2000). Woollard's work is completely missing from current-day lean management literature (Sugimori *et al.*, 1977; Shingo, 1981; Monden, 1983; Ohno, 1988; Womack *et al.*, 1990; Kimoto, 1991; Togo and Wartman, 1993; Womack and Jones, 1996; Kawahara, 1998; Fujimoto, 1999; Liker, 2004; Shimokawa and Fujimoto, 2009).

The significance of Woollard's work is his association with the introduction of a basic flow production line to assemble steel railroad coach bodies in 1904, his introduction of flow production in automobile parts manufacture E.G. Wrigley and Company, Ltd, *ca.* 1916, and his pioneering introduction of advanced flow production coupled with the development and use of innovative automatic transfer machinery (Morris Engines *et al.*, 1924) for automobile engine manufacturing at Morris Motors beginning in January 1923 (Woollard, 1925; Woollard and Morris, 1925).

The history of modern progressive operations and production management practices generally begins with the work of Frederick Winslow Taylor starting in the late 1880s (Taylor, 1903, 1911, 1947), Frank Gilbreth at around the same time (Gilbreth, 1911), and Henry Ford in the 1910s and 1920s (Ford and Crowther, 1922, 1926; Sorensen and Williamson, 1956), then jumping to the development of Toyota's production system following Second World War through the 1970s (Ohno, 1988; Toyoda, 1985; Toyota, 1988; Womack *et al.*, 1990; Shimokawa and Fujimoto, 2009).

Henry Ford is often cited by Toyota managers and others as a principal source of influence for the development of the Toyota Production System (TPS), also known as lean production (Ohno, 1988; Womack *et al.*, 1990; Womack and Jones, 1996; Liker, 2004). This attribution, however, may have been more out of respect, admiration, and desire for future business relationships rather than actual direct influence on production methods (Woollard and Emiliani, 2009, pp. E12-E13), because the scale of Ford's operations was much too large to be of use to Toyota executives (Sato, 2008). In addition, acknowledgement of Ford may have had to do more with his overall business and management philosophy (Ford and Crowther, 1926; Ohno, 1988, p. 97).

There is little mention of Taylor's influence on TPS, which was significant (Tsutsui, 1998), and there is never any mention of the British automaker Morris Motors Ltd or the pioneering work of Frank G. Woollard as possible influences on Toyota Motor Corporation, particularly in its formative years (1933-1950). This is important because Woollard achieved flow in the mid-1920s using what we today recognize as distinctive characteristics of Toyota's production system: work cells, part families, standardized work, just in time, supermarkets, autonomation (jidoka), takt/cycle time, quick change-over, multi-skilled workers, arranging the equipment in the sequence in which value is added, etc.

In addition, Woollard understood the idea and practice of continuous improvement in a flow environment, saying that the need for modifications to the flow line "should cause no anxiety, but rather should be a matter for rejoicing [. . .] the virtue of flow production lies in the fact that it brings all inconsistencies into the light of day and so provides the opportunity for correcting them," and "[the] high visibility conferred on the company's activities by flow production will lead to unceasing and continuous improvement" (Woollard, 1954b, p. 87). To that end, Woollard gave some control to workers. They had the freedom to move between jobs (Woollard, 1925, p. 451) and to solve their own problems (Woollard, 1925, p. 463). Thus, Woollard did not see workers as brainless cogs. He realized that they were part of the system, not separate from it, and their knowledge and participation in daily problem solving was necessary to maintain and improve flow. However, Woollard's engagement of workers in daily problem solving, while perhaps innovative for its time, was rudimentary and more limited compared to Toyota's systematic development of workers capabilities post-Second World War (Yasuda, 1991; Toyota, 2001; Liker, 2004; Liker and Hoseus, 2008).

Woollard also recognized that flow production will not work properly if it is used by management in a zero-sum (win-lose) manner;, e.g. where the company benefits from process improvements but employees who are made redundant by process improvements are laid off to reduce labor costs. He recognized that in order for flow to exist, the interests of key stakeholders must not be marginalized. Flow must cause no harm; if it does, then material and information will not flow. This is particularly insightful and a distinctive aspect of Woollard's progressive management practice. He understood the importance of what is today called the "Respect for People" principle in lean management (Toyota, 2001; Emiliani *et al.*, 2007; Emiliani, 2008), and the record indicates he was a warm-hearted person, a humane manager, liked by workers, and an inspiring leader (Woollard, 1954b, Chapter 16, 1955b; Cole, 1976; Bramley, 2010a, b). His 18th and final principle of flow production states: "The system of production must benefit everyone – consumers, workers, and owners" (Woollard, 1954b, p. 51) – and today, we would also include suppliers and communities. In other words, flow cannot exist when senior managers are committed to a zero-sum mindset.

Woollard's groundbreaking work is of great importance because it significantly expands our understanding of progressive management practices in the British motor industry in the mid- to late-1920s, and also informs us of new contributions that may have helped shape today's practice of lean management. Woollard's remarkable work in flow production and his prescient innovations in industrial automation deserve a prominent place in the history of industrial management, production engineering, and automation. In addition, his work is clearly congruent with today's lean management principles and practices.

This paper seeks to present an overview of Frank Woollard's life and work based upon:

- Newly discovered papers that describe engine production methods both before (Hotchkiss, 1922a, b, c, d, e) and after Woollard's arrival at the Morris Engines Ltd (Woollard and Morris, 1925).
- Newly discovered archives obtained from The Institution of Mechanical Engineers (IME, 2009), Birmingham Central Library (BCL, 2009), and David Bramley (Bramley, 2010a).
- New first-hand testimony from a close friend, David Bramley, age 96 (Bramley, 2009a, b, 2010a, b), and from a long-time family friend Murdoch Matthew (Matthew, 2009).

- Extensive discussions with leading British motor industry historians (Barraclough, 2009; Wood, 2009, 2010).

In addition, this paper seeks to place Woollard's work in the broader context of the evolution of lean principles and practices. It is hoped that this will inspire academics to mine the references contained in this paper and conduct additional research on Woollard's life and innovative work. It is also hoped that management practitioners will gain greater insights into the history and evolution of progressive operations and production management practices.

The life of Frank G. Woollard

Frank Woollard was born in London on 22 September 1883, the son of George and Emily Woollard. His father was a first footman and butler to grand households in London, while his mother was a kitchen maid. Later his father was general steward – head butler, cook, and domestic staff manager – to C. Hoare & Co., England's oldest private bank, located on Fleet Street in London, and earned £86 per year in the early 1900s (Hoare, 2009; Hunter, 2009).

Woollard was educated at City of London School in the mid-to-late 1890s (Woollard, 1955a). In 1899, he began a five-year apprenticeship to noted Steam Locomotive Designer and Builder Dugald Drummond, Chief Mechanical Engineer at London and South Western Railway in Eastleigh, working on rail cars. His father, George, paid £50 to the railway in fall of 1899 for his son's apprenticeship (Drummond, 1899). Woollard participated in the design and development of the Clarkson steam omnibus, a steam-powered city bus. In 1904, London and South Western Railway introduced a simple flow production line to assemble steel railroad coach bodies, which is where Woollard first-gained experience with flow production. Subsequent to that he worked in the design office at Weigel Motors Ltd, London, and then in 1910 joined E.G. Wrigley and Company, Ltd, Birmingham, a maker of gearboxes, axles, and steering components to various automobile companies, as Chief Draftsman (Jarman and Barraclough, 1965, p. 21).

In 1911, Woollard married Catherine Elizabeth Richards (born in 1878), a talented pianist and singer, music teacher, and public speaking coach, daughter of Henry Richards, an engraver. Their first child, a son named Peter, was born in 1912 but died in 1914. A daughter, Joan Elizabeth was born in 1916 (Granelli, 2000).

Woollard first met William Richard Morris in 1912 while working at E.G. Wrigley and Company, Ltd (Woollard, 1925, p. 449). Their initial meetings concerned the design and supply of axle and steering components to W.R.M. Motors Ltd, the forerunner of Morris Motors Ltd, for the "Bullnose" Morris Oxford motorcar. The two would meet frequently over the next few years to discuss details of auto parts design and production, and built a close personal relationship. In 1914, Woollard assumed responsibilities as a production engineer and experimented with improving machine shop layout. He reorganized production from batch to a simple form of flow to meet an increase in orders for automobile components. Woollard became a member of The Institution of Automobile Engineers, London, in 1915 and enlisted in His Majesty's Army (reserve) on 10 December at the age 32 to support armament production during the war. Around 1917, Woollard become a Director and Chief Engineer, then Assistant Managing Director in 1918 of E.G. Wrigley and Company, Ltd.

Woollard received a Member of the Order of the British Empire Award in 1918 for his work on improving the design and production of tank gearboxes, which had previously been the bottleneck in tank production at E.G. Wrigley and Company, Ltd This civil award for service in connection with the war effort was recommended to the Monarch by Winston Churchill, Minister of Munitions. Woollard left E.G. Wrigley and Company, Ltd in late 1922, as the company had encountered financial difficulties.

After First World War, the French firm of Hotchkiss et Cie, who had a factory in Gosford Street, Coventry, agreed to make engines and gearboxes for Morris Motors Ltd These engines were copies of American designs produced by The Continental Motors Corporation of Detroit, Michigan (Seymour, 1999, pp. 35-6; Jarman and Barraclough, 1965, pp. 57-63). William Morris became interested in purchasing the Hotchkiss factory in the fall of 1922 because its management would not commit to supplying the larger quantity of engines and gearboxes that Morris needed. Morris asked Woollard to inspect the facility in early November 1922 and inform him of his assessment. Woollard's overall appraisal of the machines and supporting production equipment was favorable (Woollard, 1922), and in January 1923 William Morris bought the Hotchkiss et Cie engine plant, which then became Morris Engines Ltd, and known later as Morris Motors Ltd, Engines Branch.

Morris recognized Woollard's creative design skills, innovative flow production ideas, and management capabilities, and named him General Manager of Morris Engines Ltd starting in January 1923. With Morris's strong encouragement and financial support, Woollard immediately led the reorganization of engine production from batch to flow, increasing output from less than 300 units per week in January 1923 to 600 units per week by December 1923, and to 1,200 units by December 1924 (Woollard, 1925, 1955c). The major changes in production system design – work schedule, factory layout, facilities upgrades, and the purchase and installation of innovative new machinery – took place remarkably quickly, over a period of less than two years.

Flow production was initially facilitated by the use of manual transfer of material between machining operations and hand clamping, produced in collaboration with Herbert Taylor, Chief Engineer, and Leonard Lord, Machine Tool Engineer (and the future chairman of both the Austin Motor Company, Ltd and British Motor Corporation Ltd). Soon thereafter, Woollard, Taylor, and Lord designed the first automatic transfer machines for producing gearbox cases and flywheels (Morris Engines *et al.*, 1924), with the support of engineers from the machine tool builders James Archdale & Company, Ltd, Birmingham, and Wm. Asquith, Ltd, Halifax. However, being in advance of their time, reliability problems with the electrical, pneumatic, and hydraulic systems, forced a return to manual transfer and hand clamping in late 1925 (Woollard, 1953a).

Woollard's success in increasing engine output, which had been the bottleneck in automobile production, earned him, in 1926, the post of Director of Morris Motors (1926) Ltd when this company acquired both Morris Motors Ltd and Morris Engines Ltd, the latter business being renamed as Morris Motors Ltd, Engines Branch (Andrews and Brunner, 1955, p. 175). From this position, he was a principal participant in the growth of Morris Motors Ltd, which achieved a commanding 34 percent market share in 1930 (Andrews and Brunner, 1955, p. 185). Morris Motors Ltd was the premier UK automaker at the start of the 1930s. Management was proud of its achievements in automobile production and particularly in engine production.

During his visit to the Morris Engines Ltd, ca. 1925, the then Chief Production Engineer of Ford Motor Company said that the automatic transfer machines were 20 years ahead of their time (Anonymous, 1957). Woollard's engine plant was a model for British industry and open to the public (Seymour, 1999, p. 38) and to representatives from other automakers for tours (Andrews and Brunner, 1955, p. 188*n*). In addition, Woollard wrote numerous papers published in widely read journals that presented the details of Morris Motors' flow production methods (Woollard, 1924, 1925; Woollard and Morris, 1925; Woollard and Emiliani, 2009).

On 15 June 1931, soon after the onset of the Great Depression in the UK, Woollard resigned from Morris Motors Ltd, Engines Branch (Woollard, 1931a, b, c, d, e). The precise reason(s) for Woollard's resignation have remained a closely guarded secret for nearly 80 years. His personal secretary, Mrs T.C. Daubney (Cole, 1976), daughter Joan, colleagues, and family friends were unwilling to say why a man so successful as Woollard would resign his prestigious position, leading to speculation that it was due to a personal indiscretion (Andrews and Brunner, 1955, p. 196).

Woollard's archives reveal that his resignation was dictated by William Morris's deputy, Edgar Blake, in accordance with William Morris's wishes (BCL, 2009). The reason for his forced resignation, however, is unclear, but likely due to a combination of several factors including:

- conflicts over labor policies;
- increases in production costs;
- manufacturing difficulties, service problems, and high guarantee claim costs with the troublesome new 14.9 horsepower (hp) (RAC) model L.A. side valve six-cylinder engine for the 1930 model year Oxford Six motor car;
- rivalries with colleagues W. Peach (Engines Branch superintendent) and Arthur Rowse (General Manager of Cowley Works);
- unauthorized research and development projects;
- "'Lavish' office equipment" and "alleged dissatisfaction of the staff" (Woollard, 1931b);
- a difference of personal opinion between Woollard and Morris; and
- a change in reporting relationship, loss of access to Morris, and loss of influence.

According to Woollard's long-time friend, David H. Bramely (Bramley, 2009a, b), Woollard was forced to resign due to service problems and costs associated with the new L.A. engine, a compact six-cylinder engine. The fact that Arthur Pendrell, Chief Engine Designer who reported to Woollard (Cole, 1976), was sacked at exactly the same time as Woollard (1931d) suggests that this was indeed the cause. However, the archival record surrounding Woollard's resignation is complex, and Woollard himself never revealed in his letters exactly why he was forced to resign (BCL, 2009). Extensive conversations with British motor industry historians (Barraclough, 2009; Wood, 2009, 2010) indicate more than one factor was likely in play.

William Morris was known to have greatly valued loyalty among his staff. He said in a radio interview:

> When thinking over any man for an executive position, the first thing I want is a loyal face. If a man isn't going to be loyal, neither of us will get on together (BBC, 1977).

While Woollard indeed had a loyal face, it is possible that he did one or more things, perhaps in concert with Arthur Pendrell, that Morris judged to be disloyal.

Woollard was highly creative and innovative. He liked to take risks, among them undertaking projects without William Morris's knowledge, and perhaps did something that he thought was within his duties at a General Manager of the Engines Branch and as a Morris Director, but turned out to be problematic in some significant way and which upset William Morris. Woollard was blindsided by his dismissal, saying in a letter, "The blow was like a thunderbolt from the blue sky [. . .]" (Woollard, 1931a). As a result of his resignation, Woollard was unable to continue what "I had come to regard as my mission in life [industrial management and flow production]" (Woollard, 1931a), and his nearly 20-year friendship with William Morris abruptly ended.

Woollard struggled to find work after leaving Morris Motors Ltd, likely due to poor employment prospects during the Great Depression. In addition, Woollard's salary while employed by Morris Motors was nearly £3,500 per year in 1930-1931, equal to about £660,000 in 2009 (MW, 2009), and likely 5-10 percent greater in the years before the Great Depression as a substantial portion of his salary was based on production output. Apparently, other employers were unwilling to match that salary. Finally, Woollard's reputation was likely severely damaged by having been forced to resign.

In 1932, Woollard became Managing Director of Rudge-Whitworth Ltd, Coventry, a failing motorcycle manufacturer that Woollard was unable to help turn around in the four years he worked there. Motorcycle production ceased in 1939. Woollard accepted an appointment in 1936 to join Birmid Industries, Ltd as Director of Birmingham Aluminum Castings Co., Ltd, Birmingham, and Midland Motor Cylinder Co., Ltd, Smethwick. On 5 March 1941, Woollard's wife Catherine died of cancer in November 1941, age 63, and was laid to rest in the churchyard cemetery of St. Peter's Church, Wootten Wawen, Warwickshire, UK.

Woollard became President of The Institution of Automobile Engineers, London, in 1945, a post he held until 1947 when he led the merger between The Institution of Automobile Engineers and The IME, London. He then became the first chairman of the Automobile Division of The Institute of Mechanical Engineers, London. He was also a founding member of the British Institute of Management in 1947, whose name was changed to Chartered Management Institute in 2002 (CMI, 2009).

Woollard was Chairman of the Executive Committee of the Aluminum Development Association from 1949 to 1952 and Chairman of the Council for the Zinc Alloy Die Casters Association from 1952 to 1956. He also served as a Consultant to Austin Motor Company, Ltd on the use of light alloys for automotive applications. Woollard retired from active business in August 1947 but worked as a consultant to British industry on flow production and automation, writer, and lecturer at Birmingham area universities. His interests in retirement included "studies in advanced methods of flow production and in the human factor in industrial relations [. . .] and education for industrial administration" (Woollard, 1955a).

In early 1951, Woollard was hired by David Bramley, head of the recently formed (1947) Department of Industrial Administration at Birmingham Central Technical College, Birmingham UK (now Aston Business School, Aston University), to deliver a six-part course on the principles of flow production. Woollard's course, "A short lecture-discussion course for senior industrial executives on basic principles of flow production," was delivered for the first time between April and June 1951 and was attended by 72 managers from 42 companies representing a wide range of UK industries (Woollard, 1951).

Bramley, born on 19 November 1913 and raised in London, held various production control and management positions in the British rail, auto, and aircraft industries before entering academia. Bramley first met Woollard in the summer of 1930 when, as a 16-year-old an indentured engineering apprentice (Bramley, 1978), he attended a lecture given by Woollard at an Institution of Automobile Engineers meeting in London and later toured Woollard engine manufacturing facility in Coventry (Bramley, 2010a, b). Despite a 30-year age difference, he and Woollard became close friends and they attended concerts and the theatre together (Bramley, 2009b). Bramley's production engineering and management career was mentored by Woollard, and he held Woollard in the highest regard for, among other things, his mentoring and support of young engineers and his ability to organize people with differing agendas and bring them together to achieve common goals (Bramley, 2010a, b). Bramley was Co-Executor of Woollard's estate, along with Woollard's daughter Joan, an artist (HMCS, 1957; Granelli, 2000).

At the urging of David Bramley, T.U. Matthew (Head of Department of Engineering Production, University of Birmingham), and others, Woollard wrote a series of articles based on the six-part lecture-discussion course which were published in the journal *Mechanical Handling* (Woollard, 1952a, b, c, d, e, f, 1953a, b, c, d). These articles became the basis for his 1954 book, *Principles of Mass and Flow Production* (Woollard, 1954b), followed by a short monograph highlighting Woollard's 18 principles of flow production (Woollard, 1954a).

Woollard wrote extensively on flow production, industrial automation, and related topics, having authored no less than 27 papers in national periodicals, conference proceedings, and international journals between 1924 and 1956, 11 of them published between 1924 and 1925. (Woollard and Emiliani, 2009). These papers, published with William Morris's explicit approval, clearly indicate a strong desire to share the details of their innovative continuous flow production processes with others and also to showcase British industrial prowess. In addition, Woollard held 13 UK patents and one US patent. Thus, Woollard's great creativity and innovativeness is demonstrated across a wide range of activities, from part design, production system design, machine tool design and industrial automation, and progressive industrial management.

In 1956, Woollard was introduced to economist Aubrey Silberston by David Bramley, who was conducting research for a book on the economic history of the British motor industry from its inception to 1957 (Maxcy and Silberston, 1959). According to Silberston, Woollard was very eager to talk about flow production (Silberston, 2009). Thus, Woollard remained an enthusiastic proponent of flow production until the end of his life.

Frank George Woollard died on Sunday, 22 December 1957 at the age of 74, and was buried next to his wife Catherine in St. Peter's Church, Wootten Wawen, Warwickshire, UK. His obituaries recognized him as one of the fathers of the British motor industry (Anonymous, 1957, 1958). He was survived by his daughter Joan (Granelli, 2000), who passed away on 30 January 2008 at the age of 92 and was buried in the same churchyard cemetery near her father and mother (Mortimer, 1999).

Flow production at Morris Motors

Newly discovered papers published in the spring and summer of 1922 describe the engine and gearbox production methods used at Hotchkiss et Cie (Hotchkiss, 1922a, b, c, d, e).

A 1922 conference proceeding paper authored by Herbert E. Taylor, Chief Engineer at Hotchkiss, provides similar information on the methods of production, but also speculates in the last few pages of the paper that an entire factory could be conceived of "as a colossal automatic machine" (Taylor, 1922, p. 250), which would utilize manual and mechanical conveyance devices and result in a much more compact "cubic" factory – an idea which Woollard found inspiring and complimentary to his own ideas on flow production. These papers provide detailed information on the methods of production approximately one year before William Morris bought and took control of Hotchkiss et Cie in January 1923 and establish the initial condition of the factory prior to the purchase being finalized in May 1923. It therefore puts into context the significance of the changes made by Woollard beginning in January 1923 to achieve flow production.

The manufacturing method used at the Hotchkiss et Cie factory *ca.* 1921-1922 was unambiguously batch-and-queue (Hotchkiss, 1922a, b, c, d, e). The descriptions of manufacturing processes focus on the workpiece, equipment, and tooling as stand-alone operations. A diagram showing the arrangement of the plant shows process villages characteristic of separately positioned batch processing. The processing times for each operation show large cycle-time mismatches, with cycle times ranging from 2 to 35 minutes, and no discussion of efforts to balance cycle times. A 25-minute cylinder block milling operation was performed using two machines, while a 7-minute drilling operation was performed using two machines, for example.

There is only passing mention of the methods used for material handling. The "progress board," a visual record of the amount of raw material and finished goods stock held for each engine component, shows considerable variation between these two types of inventory for individual components, i.e. large amount of raw material and small quantity of finished goods, or vice versa. The quantity of finished components varied considerably, with shortages of 50 percent for some parts and surpluses of 200 percent for other parts, as is typical in batch-and-queue processing.

Factory output under these conditions was 100 units per week (11.9 hp engine and gearbox), with plans to increase output to 200 per week. Recall that William Morris wanted Hotchkiss management to produce 500-600 engines and gearboxes per week, but they would commit to only 300 per week (Andrews and Brunner, 1955, pp. 127-8). Given the method of production, it is no surprise that Hotchkiss management was reluctant to double output. They would have had cost problems due to the increases in raw material and finished goods inventories.

In summary, the Hotchkiss factory utilized the batch-and-queue production method, and there was no evidence of flow production having been established by Henry Ainsworth, General Manager, Herbert Taylor, or Leonard Lord. However, Taylor and Lord, who by April 1922 was Assistant Chief Engineer (Seymour, 2006, p. 170), were principal participants in Woollard's efforts to establish flow at the Morris Engines Ltd Woollard, who replaced Henry Ainsworth, promoted Lord to the position of Machine Tool Engineer, responsible for the design and purchase of new machinery that would facilitate flow production (Seymour, 2006, p. 170), manual and automatic transfer machines (Morris Engines *et al.*, 1924).

The focus of Woollard's work was on achieving flow in processes upstream of final automobile assembly, principally to reduce queue time and to produce a greater output from a fixed quantity of resources, to support the rapid sales growth of Morris Motors Ltd He also wanted to reduce the costs associated with raw material and finished goods inventories to help achieve Mr Morris's goal of frequent price reductions for his cars, while at the same time improving their specification annually. For example, according to Morris sales catalogs, the price of a Morris Cowley two-seater was reduced from £278 in 1923, the year that Woollard joined Morris Engines Ltd, to £160 in 1930. Lower cost engines (Woollard, 1931e) helped achieve these price reductions which not only greatly extended the reach of Morris's vehicles to lower income customers but also gave Morris a substantial market share as many of his competitors were unable to match the prices of his cars. Flow production offered numerous benefits with respect to helping to achieve broader business objectives of meeting customer demand, reducing capital intensity, and improving labor relations (Woollard, 1925, 1954b).

Woollard clearly recognized the limitations of batch-and-queue processing, as well as the differences between Ford's Model T high volume flow production system and the new lower volume flow production system that Woollard sought to create. As might be expected, Woollard was very aware of the production methods used by US automakers and the machines made by American machine tool makers. He cites their influence and that of the American technical press (Woollard, 1925, p. 419) for providing useful information which surely shaped his ideas for flow production (Arnold and Faurote, 1919). However, Woollard is careful to point out that he and his staff developed their flow production system without ever visiting automakers in the USA, as most others had done. He proudly notes that his low volume flow production system and associated automatic transfer machinery were entirely British efforts borne of British ingenuity (Woollard, 1925, p. 419). It helped greatly that William Morris, as owner of the company, was an enthusiastic supporter of new production methods and a financier of new machine technologies.

Woollard also understood that Ford's production system was the result of unique circumstances; a very large home market and robust sales that permitted an incredible level of vertically integrated production activities. Ford's approach to large-scale production could not be replicated by Morris Motors due to practical considerations such as limited capital, smaller markets, and diverse consumer needs (Tolliday, 1998). Instead, Woollard sought to go beyond large-scale mass production (as did Toyota two decades later) by adapting Ford's production system to achieve flow production without extensive vertical integration and within the context of their respective domestic markets – much lower sales volumes than Ford and more diverse customer needs. Note that Morris Motors Ltd produced over 55,000 vehicles in 1925 (Andrews and Brunner, 1955, p. 112), while in the same year Ford Motor Company produced 1.9 million Model Ts (Houston, 1927). In contrast, Toyota Motor Corporation would not produce more than 55,000 vehicles in a single year until 1957 (Toyota, 1988, p. 461).

Woollard knew that flow had to be achieved in sub-component assembly and parts manufacturing, and even into raw material production, to support flow in single-model or mixed-model final automobile assembly lines. Woollard's awareness in 1925 that all processes must be connected "from the design [. . .] up to and even beyond the sales stage" (Woollard, 1925, p. 420), illustrates a depth of understanding of flow that was unique for its time – though this condition was not fully achieved across the Morris Motors enterprise. This is an aspect that managers who attempt to establish flow today typically do not understand, mistakenly thinking that achieving flow in operations is sufficient (i.e. operational excellence).

Academics who cite Woollard's work in flow production make reference principally to his 1925 conference proceeding paper, "Some notes on British methods of continuous production" (Woollard, 1925) or his 1954 book, *Principles of Mass and Flow Production* (Woollard, 1954b). The series of papers authored by both Woollard and Morris have yet to be studied by academics (Woollard and Morris, 1925). These new papers provide additional details of their flow production system, and include a diagram of the Morris Engines Ltd factory layout which has been clearly redesigned for flow. While factory floor space more than tripled to accommodate increased production, the floor space per unit decreased by 70 percent.

The papers "Morris production methods" (Woollard and Morris, 1925), along with Woollard's 1925 paper "Some notes on British methods of continuous production" (Woollard, 1925), reveal that most of the components of today's lean production practices were in place. While readers are referred to those papers for the details, some of the pertinent features of Woollard's production system are summarized here.

Unlike the Hotchkiss batch-and-queue production system, Woollard descriptions of the manufacturing process focuses on achieving continuous flow and connected or integrated operations. The arrangement of the plant has been thoroughly reorganized to facilitate flow for component manufacturing and assembly. According to Woollard, "The whole of the plant is organized round the cylinder block [. . .] and all other components, sub-assemblies, and major assemblies flow towards this" (Woollard and Morris, 1925, p. 776).

Woollard was very concerned about cycle time mismatches and made all operations equal in duration. The cycle time for machining in the automatic transfer machinery was four minutes. It is not clear how this figure was arrived at, but it was likely a response to robust automobile sales, which more than doubled between 1923 and 1925 (Andrews and Brunner, 1955, p. 112). Woollard notes that "Four minutes is the standard time-cycle to-day, but it may be altered as required" (Woollard, 1925, p. 463). This indicates the use of cycle time as a takt time.

With regard to material deliveries, Woollard says that they "must be delivered to time so that there shall be no shortage or glut" (Woollard, 1925, p. 422). The phrase "delivered to time" obviously has similar, if not the same, meaning as "just-in-time," by which Kiichiro Toyoda meant: "Just make what is needed in time, but don't make too much" (Toyoda, p. 58). In addition, Woollard used a supermarket-type system to store engine blocks and limit inventory to a four-day supply, just as Toyota would do more than two decades later (Ohno, 1988, pp. 25-7). He made these and other improvements, such as milk runs, to control inventories and reduce capital outlays.

The main features of Woollard's flow production practice include (using contemporary names and characterizations):

- part families;
- U-shaped work cells;
- multi-skilled workers;
- standard materials, products, and machine tools;
- work to a takt time (cycle time in this case);
- standardized work;
- just-in-time;
- supermarkets;

- autonomation;
- visual controls; and
- quick changeover.

These practices, of course, are typical of that found in lean production. Woollard's pioneering work in low volume production suggests that to achieve flow, managers must discover these innovations by themselves or through the pioneering work of others. Flow is the common denominator that drives every manager to the same principles and set of practices.

Notably absent was a pull system using kanban (instruction) cards (Monden, 1983, 1998; Ohno, 1988), which appears to have been a Toyota innovation (Sugimori *et al.*, 1977). Autonomation (jidoka), developed by Toyota in 1924 (Toyota, 1988, p. 34), was probably discovered independently, as may have been the idea for supermarkets from Ohno (1988, p. 26). Just-in-time, however, was practiced in the USA (Schwartz and Fish, 1998) and UK (Woollard, 1925) auto industry prior to Kiichiro Toyoda having thought of it in 1937 (Toyota, 1988, p. 69).

Woollard's work in flow production in the mid-to-late 1920s pre-dates Kiichiro Toyoda's interest in flow production by almost 15 years. An important question obviously arises: "Was Kiichiro Toyoda influenced by the work of Frank Woollard and by Morris Motors?" A close examination of the published record, corporate histories, timing of events, and a visit by Kiichiro Toyoda to the UK in early 1930 suggest that he may have known about Woollard's work and that it could have influenced him and other Toyota managers, such as Eiji Toyoda or Taiichi Ohno, in their quest to develop their own flow production system (Woollard and Emiliani, 2009, pp. E-7 to E-18). The evidence for this, while circumstantial, is very strong.

Woollard believed that machinery had an important role to play in facilitating flow production. He thought that automatic transfer machines were the logical extension of manual transfer devices and that they would further enable and improve continuous flow if applied judiciously. This proved to be correct, as automatic transfer machines became common in the global automobile industry starting in the late-1940s and early 1950s (Daito, 2000; Hounshell, 2000a, b; Zeitlin, 2000).

Woollard, however, advised caution when it came to the use of automatic transfer machines in factories, saying: "The machines are only incidental to the whole organization of the factory" (Woollard, 1925, p. 441) and that "it must not be imagined that I suggest special machines as the essential method of attacking the continuous production problem" (Woollard, 1925, p. 462). Later he warned people "against that dangerous hobby of falling in love with mechanism for its own sake" (Woollard, 1954b, p. 14). Thus, machines can enable flow, but are not fundamentally necessary for the objective of achieving flow.

Overtime, Woollard developed a set of principles for mass and flow production, numbering 18 items in the end, as shown in Table I (Woollard, 1954b, p. 51). Each principle relates directly to our current day understanding of lean production. However, Woollard's expression of the 18 principles of flow production would today be characterized as a combination of the two lean principles, "Continuous Improvement" and "Respect for People," and various technical lean practices whose origins most of which are attributable to Frederick Taylor (Taylor, 1903, 1911; Emerson and Naehring, 1988; Shimokawa and Fujimoto, 2009, p. 133).

1.	(a) Mass production demands mass consumption (b) Flow production requires continuity of demand
2.	The products of the system must be specialized
3.	The products of the system must be standardized
4.	The products of the system must be simplified in general and in detail
5.	All material supplies must conform to specification
6.	All supplies must be delivered to strict timetable
7.	The machines must be continually fed with sound material
8.	Processing must be progressive and continuous
9.	A time cycle must be set and maintained
10.	Operations must be based on motion study and time study
11.	Accuracy of work must be strictly maintained
12.	Long-term planning, based on precise knowledge, is essential
13.	Maintenance must be by anticipation – never by default
14.	Every mechanical aid must be adopted for man and machine
15.	Every activity must be studied for the economic application of power
16.	Information on costs must be promptly available
17.	Machines should be designed to suit the tasks they perform
18.	The system of production must benefit everyone – consumers, workers, and owners

Table I. Woollard's principles

Woollard expands on the importance of principle 18 by saying:

> Unless the eighteenth principle is satisfied the [flow production] system cannot reach full stature and, if it does not, the equipment and appurtenances necessary for flow production will not be utilized to the full. They might even, in some instances, become an embarrassment. This principle of "benefit for all" is not based on altruistic ideals – much as these are to be admired – but upon the hard facts of business efficiency (Woollard, 1954b, p. 180).

Woollard is warning managers that flow production will not function properly if it is used in a zero-sum manner. In the current-day practice of lean management, principle 18 is called the "Respect for People" principle. It delivers the same message; that managers should not blindly pursue the use of lean tools to achieve company objectives at someone else's expense. The uniqueness of lean management, and of flow production, compared to conventional batch-and-queue management, is that it must be operated as a non-zero-sum management system. Failing to recognize this as a critical factor, most managers struggle in their efforts to create continuous flow and are ultimately unsuccessful.

The British motorcar industry continued to prosper until the onset of Second World War when it and other industries were converted to the manufacture of products to support the war effort. The post-Second World War material supply situation caused restrictions in the production of automobiles until the early 1950s. While sales and production eventually increased to pre-war levels, the post-1950s British automotive industry began a protracted period of decline, reorganization, and bankruptcy.

Unfortunately, innovations in production methods and machinery are not sufficient to ensure long-term company survival, as was the case with Morris Motors Ltd, which eventually ceased to exist (Maxcy and Silberston, 1959; Wood, 1988; Williams *et al.*, 1994; Foreman-Peck *et al.*, 1995). Companies – their managers and employees – must excel at many other business processes including responding to the voice of the customer with new designs, short cycle-time product development, improving auto parts durability, introducing new automotive technologies, updating established products frequently, distribution, sales and marketing, and aftermarket service. The production system alone will not make a company successful.

Summary

Frank George Woollard successfully established flow production at Morris Engines Ltd between January 1923 and late 1925, and continued to improve and operate the system until mid-1931. The methods used to achieve flow production are remarkably similar to Toyota's production system, also known as lean production, inclusive of innovative materials handling machinery. While Woollard's work has long been forgotten, it is possible that in his day there may have been widespread recognition of his flow production method within and outside of the automobile industry. Other companies may have adopted his methods, likely without attribution, which might explain why his work fell into obscurity post-1957.

It seems that Woollard thought his flow production method was more-or-less complete in its design and operation (Woollard, 1954b). One could view his method as a logical next step in the evolution of what we today call lean production. In that sense, the system design and operation may have indeed been complete, and that it would be up to others, based on Woollard's work or independently, to develop improvements such as kanban to further facilitate flow. However, as Toyota's 2008-2009 inventory glut has taught us the use of kanban does not automatically guarantee responsiveness to changes in customer demand. Instead it can be used as part of a push production system.

Woollard's practice of continuous improvement appears to be non-specific, meaning that the process for improvement-lacked clear definition. Improvement was probably rooted in Taylorist industrial engineering techniques, as is modern-day kaizen (Imai, 1986, 1988, 1997), but the specific process for its application remains unknown. The opportunity to systematize continuous improvement activities would apparently be left to others (Huntzinger, 2005; Imai, 1986).

Woollard's forced resignation leaves open the question of whether or not he and his colleagues would have developed innovations such as kanban or systematized continuous improvement. Had his career not been cut short, it would have been interesting to know how or if his flow production system would have evolved and whether he would fall victim to backsliding as is so common. In most cases, flow production reverts to batch-and-queue, or a hybrid of batch-and-queue and lean, within two to ten years after the innovator leaves the company (Emiliani *et al.*, 2007). The specific production techniques in use at Morris Motors post-Woollard are unclear, partly because the new managers were not prolific writers as Woollard was and they had essentially no innovations in production management to write about.

When people discuss the origins of lean management, the conversation always includes Ford Motor Company and its leaders Henry Ford and Charles Sorensen, and Toyota Motor Corporation and its leaders Kiichiro Toyoda and Taiichi Ohno. Largely unknown to management historians and practitioners post-1957, the work of Morris Motors and its leaders William Morris (Lord Nuffield) and Frank Woollard, done between the work of Ford and Toyota, fills an important gap in the literature on the history of flow production and of the British motor industry. The authors suggest that the timelines for discoveries and attributions of key accomplishment in lean management must be revised (see timeline in Ohno, 1988, for example).

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About the authors

M.L. Emiliani "Bob" is an Associate Professor in the School of Engineering Technology at Central Connecticut State University where he teaches courses in supply chain management, leadership, research methods, and failure analysis of management decisions. Prior joining academia in 1999, M.L. Emiliani worked in industry for 15 years and had management responsibility in engineering (R&D, new product development) and operations (manufacturing and supply chain).

He had responsibility for implementing lean principles and practices in both manufacturing and supply networks at Pratt & Whitney. He also worked at United Technologies Corporate Headquarters. M.L. Emiliani has authored or co-authored seven books, 32 peer-reviewed papers, and three book chapters. Five of his papers have won awards for excellence. His book *Better Thinking, Better Results*, which chronicles the lean transformation of The Wiremold Company over a ten-year period, is a 2003 Shingo Prize winner. For the last four years, M.L. Emiliani has been studying and writing about the history and evolution of lean management. M.L. Emiliani served as the North American Regional Editor, *Supply Chain Management: An International Journal*, from 2005 to 2007. He is on the editorial review boards of: *Leadership and Organization Development Journal*, *Management Decision*, *Supply Chain Management: An International Journal*, and *Industrial Marketing Management* (2005-2009). He is also an *ad-hoc* reviewer for *International Journal of Operations and Production Management, Journal of Management Development*, *International Journal of Marketing for Industrial and High Tech Firms*, *Journal of Marketing Research*, *International Journal of Electronic Business*, and *Quality Assurance in Education*. M.L. Emiliani earned a BS in Mechanical Engineering from the University of Miami, an MS in Chemical Engineering from the University of Rhode Island, and a PhD in Engineering from Brown University. M.L. Emiliani is the corresponding author and can be contacted at: emilianibob@ccsu.edu

P.J. Seymour began his career by serving an Engineering Apprenticeship with Morris Commercial Cars Ltd, Birmingham, from 1959 to 1964. He then joined the Export Service Technical Department of British Motor Corporation Service Ltd, Cowley, as a Service Engineer, traveling to BMC Distributors overseas for extended periods. From 1971 to 1974, he worked for United Africa Co., as Service Manager for their Bedford and Land Rover franchises in West Africa; one year working in Nigeria and two years working in Sierra Leone. From there P.J. Seymour joined the Service Marketing Departments at Leyland Cars, Cowley, working in a small team on special projects, and then Leyland Vehicles Ltd as Distributor Development Executive, working initially in Leyland's Headquarters in London and then based in Singapore, covering the Southern Hemisphere. He next served as General Manager of Trans International, Singapore, the John Deere Distributor for Singapore and Burma. Currently, P.J. Seymour is Managing Director of Vicarys of Battle Ltd, a company that was awarded a Morris franchise in 1924. All told, P.J. Seymour lived and worked in over 40 countries. Mr P.J. Seymour is also a noted historian of the British Motor Industry, particularly of the Morris group of companies, which included the M.G. and S.U. companies. He has studied the life and work of William Richard Morris (Lord Nuffield), the development of his business since he started making bicycles in 1893, his financial situation, and his benefactions. He has authored three books: *Morris Bullnose & Flatnose Power Units* (1995), *Morris Light Vans 1924-1934* (1999), and *Wolseley Radial Aero Engines: Lord Nuffield's Thwarted Venture* (2006). He has also written many technical and historical magazine articles and is the Technical Correspondent of the Bullnose Morris Club. Mr P.J. Seymour is a Qualified Engineer and a Member of the Institute of Road Transport Engineers.