Technology on the Move:
Engineering Development on Early Main Line Railways

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Introduction

Main line railway networks expanded quickly after the opening of the Liverpool & Manchester Railway in 1830. By the end of the first decade of operation, total railway mileage had risen to 5200, of which 1500 had been opened in Britain alone, and 2800 miles in North America[1]. The expansion was made possible by rapid technical progress in all branches of railway engineering and by the equally rapid expansion of manufacturing capability and capacity, and of the contractor base for new route construction.

British engineers and manufacturing industry dominated in these earliest years, but by the mid-1840s, the 'mania' for railway building in the United Kingdom outstripped the capability of its manufacturing companies to keep up with demand, and order books lengthened significantly. Continued expansion of rail networks in Europe, initially dependent upon Britain for their equipment, stimulated the start up of new manufacturing industry, especially in France and the German states. Mileage in the United States more than tripled to 9000 miles by the end of the decade, its equipment requirements being largely met by the nation's new manufacturing industries[2].

By the end of the 1850s, rapidly expanding economic development had led to an extraordinary demand for both passenger and goods services, and railways had matured to become an integral part of the social and economic fabric of the developed world. In addition to the growing networks in Britain, Continental Europe and North America, railways were begun in other parts of the world, including India, Australia, the Middle East and South America.

Britain's main line railway network had reached 9000 miles, approaching half its ultimate length[3]. This expansion of services required a high level of output from the country's locomotive and rolling stock industries, together with its ironworks supplying large quantities of track and structural iron. Heavier trains were made possible by the installation of more substantial bridges and heavier duty track, whilst

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[1] Prof. Roger Burt, Department of History, School of Historical, Political and Sociological Studies, University of Exeter, *The Making of the Modern World*, Lecture 8, 'The Expansion of the World Economy 1800 - 1914:The Growth of World Trade', http://people.exeter.ac.uk/RBurt/exeteronly/making/Lecture8.html, accessed in November 2010; Henry Grote Lewin, *Early British Railways* (London, n.d. but 1925), p.186; John F. Stover, *The Routledge Historical Atlas of the American Railroads* (New York, 1999), p.14.

[2] Stover, *op cit*, p.16.

[3] B.R. Mitchell and P. Deane, *Abstract of British Historical Statistics* (1962 ed.,), pp.225-6, quoted in Jack Simmons and Gordon Biddle (eds.), *The Oxford Companion to British Railway History* (Oxford, 1997), p.492.

significant increases in speed were also made possible by further track improvements[4].

The more structured development of European railways, without the free market competitive drive of the British networks, suppressed demands for higher speeds. The design of track, structures and locomotives thus evolved more slowly, avoiding expensive development and manufacturing costs. The railways of North America, however, opening up land hitherto without transport infrastructure, were more basic and less expensive to build than their European counterparts. The very different technologies of simple track, timber trestle bridges and much cheaper locomotive designs contrasted with Europe's predominantly masonry and iron structures and sophisticated locomotives. This allowed available capital to be used to build a huge mileage of new routes, and some 30,000 miles of line were in operation throughout the United States alone by 1860[5].

But this broad narrative of early railway progress reveals little of the driving forces behind technological developments that led to increases in speeds and train-loads, and improvements in efficiency providing operating cost reductions. Was innovative progress achieved because it was driven by the competitive expectations of railway proprietors, or did technological innovation arise through competition between manufacturers? The railway service introduced much that was new in civil and mechanical engineering, and in major advances in manufacturing processes. These advances, covering design progress, material developments, skills transfer and legislative influences, need to be better understood as well as the impact that they made in business and economic terms.

This paper therefore discusses the opportunities for research and presentation of papers that will serve to open up debates leading to a much better understanding of the several and interactive issues that influenced technology in the respective regions of the world where main line railways first developed.

Railway Building

As civil engineers gained experience building the earliest railway routes, they were encouraged by proprietors of new rail projects to pursue more ambitious routes requiring excavation and deposit of increasing volumes of soil and rock. The relationship between locomotive design, train loads and ruling gradients for railway routes had large implications for the cost of route construction. Engineers were required not just to build a railway for immediate needs, but to anticipate how locomotive improvements and increasing train loads would be effected by ruling gradients and horizontal curvature. This important topic is however a subject that has yet to be considered by historians, and there has been no discussion on the specification of ruling gradients and line curvature that determined route selection.

Land surveyors sought alignments for new railway routes through a wide variety of different terrain whilst meeting the engineers' specifications. Although surveying was

[4] P.J.G. Ransom, *The Victorian Railway and How it Evolved* (London, 1990).
[5] Stover, *op cit*, p.20.

an essential pre-requisite of railway building, only one author has considered this work for Britain's railways[6]. Biddle has considered the surveying, managing, acquiring and disposing of railway property throughout the nineteenth and twentieth centuries. However, many further opportunities remain for a greater understanding of developing surveying techniques, and the way in which the profession expanded.

The growth in new rail routes, particularly in the 1840s, led to a huge increase in demand for surveyors' services, but from what backgrounds did the candidates come and how were they recruited and trained? How did they and the engineers gain sufficient knowledge of different rock and soil types to make judgements regarding alignments and gradients and consequential cost implications? Did the Ordnance Survey mapping of Great Britain assist with the early railway survey work? To what extent were engineers and their surveyors impeded in route selection by disapproving or opportunistic landowners?

Some of the earliest rail routes in Continental Europe were built by experienced British surveyors and engineers. But to what extent was there a dependence upon that expertise and how quickly were continental surveyors able to master the techniques of railway alignments? Did countries, such as France and the states of the German Empire, have maps comparable with the British Ordnance Survey available to them? If not, how much more difficult was their task to achieve optimum alignments? Did continental surveyors meet the same challenges from disapproving or opportunistic landowners as their British counterparts?

Whereas British civil engineers and surveyors undertook the building of many of the earliest rail routes in Canada, railway surveyors and engineers in the United States were usually from a military background[7]. What were the reasons for this - was it simply a lack of surveyors in civilian life, or was there State or national governmental encouragement to build railways as soon as possible to open up new routes for land development? To what extent were maps available for these new routes, or did surveyors develop different techniques for optimal alignments as they went?

The scale of railway construction work in the mid-19th century was immense. From the outset in the early 1830s however the number of large contractors with experience of works exceeding £100,000 in value was very limited[8]. The rapid rise in construction work required a correspondingly rapid growth in the number of contractors with expertise to undertake increasingly demanding building work, and especially the ability to provide the requisite working capital.

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[6] Gordon Biddle, *The Railway Surveyors, The Story of Railway Property Management, 1800-1990* (London, 1990).

[7] See for example Mike Chrimes, 'Alexander Mackenzie Ross', who was appointed Engineer-in-Chief of the Grand Trunk Railway in 1852, in Peter Cross-Rudkin and Mike Chrimes (eds.), *Biographical Dictionary of Civil Engineers* (London, 2008), pp.673-6. See also James D. Dilts, *The Great Road, The Building of the Baltimore & Ohio, The Nation's First Railroad, 1828-1853* (Stanford, California, 1993), p.55.

[8] Mike Chrimes, 'Selecting the Contractors' in 'London and Birmingham', in Michael R. Bailey (ed.), *Robert Stephenson – The Eminent Engineer* (Aldershot, 2003), pp.48-54.

Whilst the stories of some of the largest British contractors have been told, the industry as a whole has not been extensively considered[9]. How did firms, able to undertake extensive contracts, first emerge, and how did they demonstrate the ability to raise working capital sufficient to satisfy the railway companies that they would not fail during the progress of their contracts? Contractors employed a number of agents, foremen and reliable tradesmen, but the bulk of the workforce was formed from sub-contractors. What procedures did contractors adopt for recruitment of skilled and unskilled workmen, and how did they reconcile the optimum regular work-force with the uncertainties of sub-contracted gangs?

The building of the first continental railways was undertaken by British contractors, already skilled from their work building the first British railways[10]. As continental contractors began to undertake more of this work, however, to what extent did they seek to emulate the skills of the British firms? Did they recruit experienced agents from Britain, or did they perpetuate traditional practices of each respective country? How did these practices compare? Funding of working capital was always going to be difficult in a continental context, particularly with its volatile economy and the political upheavals of the late 1840s. To what extent was there a continuing reliance on British capital, and from what time did it become possible for European contractors to fund their operations in their respective countries?

The very different characteristics of the earliest rail routes in the United States avoided, as far as possible, expensive civil and structural works. Did this result in significant differences in the practices of the contracting industry from British and European firms? Was the construction work largely European funded or was sufficient capital available in each state to encourage the establishment of reliable contracting firms? Skills in North America were scarce at first. Did this lead to recruitment of British agents as the demand rose?

A number of the earliest Canadian railways were built by British contractors with working capital raised both on the London market and in Canada itself, although the building of the Grand Trunk Railway had proved to be a spectacular loss-making venture[11]. To what extent did this event retard the development of railway construction in Canada and what measures were taken by Canadian interests to re-establish a reliable contractor-base?

Railway Structures

The first railway bridges and viaducts constructed for the Liverpool & Manchester Railway and the other earliest railways were undertaken as larger versions of existing road bridge and canal aqueduct designs made with brick and masonry. However, as demand for new railways in Britain grew, constraints of span and headroom gave rise to the need for innovative designs, use of cast and wrought iron and development of novel construction methods.

[9] See for example Charles Walker, *Thomas Brassey - Railway Builder* (London, 1969); David Brooke, *William Mackenzie: International Railway Builder* (The Newcomen Society, 2004); and Adrian Vaughan, *Samuel Morton Peto: A Victorian Enrepreneur (*London, 2010).
[10] For example the earliest main lines in France, Walker, *op cit*, pp.38/9.
[11] Walker, *op cit*, pp.82-96.

Whilst individual structures, or those of particular engineers have been considered in recent historic assessments[12], there has been no overall consideration of the evolution of brick, masonry and timber bridges in the development years of Britain's railways. How did engineers decide on designs and materials, and to what extent were they cost driven, or driven by other considerations such as architectural statements? How did contractors develop the requisite skills to undertake building, fabrication and erection work?

In Continental Europe similarly, there was an assumption that brick and masonry bridges would be required for many of the shorter-span crossings of valleys, to provide structures that would meet the railways' long-term traffic requirements. However, in the context of planned networks determined by central governments, such as in France and Belgium, to what extent did cost considerations affect the choice of designs and materials, and was timber as widely used as it was in Britain?

In the very different circumstances in North America, the use of brick and masonry was limited and, aside from some notable exceptions, the majority of bridges were of timber, mostly in trestle form. Did this arise solely on cost grounds, given the ready availability of timber, or was the choice also due to lack of masonry skills?

Cast iron arch bridges began with Ironbridge itself in 1784, and several dozen had been employed for road use before the main line railway era. The more ambitious route requirements of the railways however soon led to innovation in iron bridge spans. As early as 1830, the Liverpool & Manchester Railway itself was confronted with the need for innovation with its restricted headroom over Water Street in Manchester. The pioneering design work of Eaton Hodgkinson and the foundry expertise of William Fairbairn resulted in the first use of iron bridge beams[13]. Thereafter, the use of cast iron for bridges on railway routes depended largely on the work of individual engineers, without professional consensus. What, therefore, were the issues which influenced the selection of the material? Although cost clearly played a major part in any design assessment, different engineers had different preferences. Was this professional experience alone, or were other influences at work, including relationships with foundry engineers such as Fairbairn?

The introduction of structural wrought iron and subsequent improvements in rolling and construction methods were largely driven by the growing requirements for bridges and viaducts of longer spans and heavier train loads. However, again there was no initial consensus in its application, and it was accompanied by several parallel design streams, a number of which, imposing as they were, were destined not to be pursued beyond the mid-century[14]. What therefore were the influences within the profession that determined the use of wrought iron? To what extent did improvements in rolling plate and sections, and other manufacturing processes make possible the greater application of the material, or did the more demanding

[12] For example Ted Ruddock, 'Masonry Structures' in Bailey (2003), pp.337-354; and Steven Brindle, *Brunel: The Man Who Built the World* (n.d. but 2005), pp.148-179.
[13] R.S. Fitzgerald, *Liverpool Road Station, Manchester*, (Manchester, 1980), pp.21-28.
[14] See for example James Sutherland, 'Iron Railway Bridges', in Bailey (2003), pp.302-335; John Rapley, *The Britannia Bridge 1845-1850* (Institution of Civil Engineers, London, 1999); and Brindle (2005), 148-179.

requirements for bridge applications themselves dictate the introductions of these improvements?

Several of the Continental European rail routes were undertaken by British engineers, such as Joseph Locke, and their structures thus reflected British practice[15]. However, as continental engineers increasingly took on railway-building responsibilities, did the development of iron bridge designs follow closely the evolution of designs in Britain, or were there independent initiatives? How quickly did continental manufacturers achieve the expertise of British industry, and was there a transfer of skills or independent development?

The introduction of several wrought iron truss designs from the 1850s, with their weight and cost reducing advantages, resulted in an international consensus that took the railway designs through to the steel era later in the century[16]. Were the truss designs merely the initiative of a new generation of engineers, including and especially those in the United States, or had manufacturers achieved new levels of understanding of the material to offer the improvements for more widespread application?

Engineers were also called upon to reduce the cost of many routes by the use of timber bridges, with both stone piers and of trestle form. This was in anticipation of their eventual replacement by more substantial structures as train loads increased and income allowed. Although leading engineers, including Robert Stephenson, Brunel and Locke used timber extensively on their early lines, there has been no comprehensive review of early timber bridge design and development in the British context. Under what circumstances was timber adopted, what forms did they take, and what types of timber were used? Was the knowledge of timber bridges in Britain and North America shared, or was there parallel design progress on the two sides of the Atlantic?

Architecture

The importance of architecture in railway buildings and other structures was apparent from the beginning of the main line railway era, and bold statements were made by the selection of imposing designs. The Liverpool & Manchester Railway's stationary engine-house at Edge Hill, Liverpool, housing the engines for drawing the trains from that city's termini, was anything but a utilitarian building. It was incorporated within an ornamental arch, in the then-fashionable Moorish form, as a spectacular gateway into Liverpool[17].

As main line railways became profitable and stimulated economic development, directors sought the services of architects to provide prominent and impressive buildings and structures. None was more symbolic than the propylaeum, or 'Doric Arch', at Euston station on the London & Birmingham Railway, which took over the

[15] N.W. Webster, *Joseph Locke Railway Revolutionary* (London, 1970).
[16] J.G.James, 'The Evolution of Iron Bridge Trusses to 1850', *Transactions of the Newcomen Society*, Vol.52 (1980-81), pp.67-101.
[17] Henry Booth, *An Account of the Liverpool and Manchester Railway* (Liverpool, 1830, re-published London, 1969), p.50.

theme of gateway to a new era[18]. But what were the main functions of this architectural splendour? Was it to impress shareholders or passengers, or both? Were these architectural messages similarly adopted in all the Continental European countries and in North America, and if not, what were the differences in each country that determined the choice?

Did railway architecture rank highly in mainstream architectural progress, employing the leading architects in Britain and Continental Europe, or was there a hierarchy that saw successful railway architects progress on to other design opportunities with major public buildings? North American railways are characterised by their pioneering role in opening up large land areas without the need for architectural embellishment. When did the early railroads begin to feel sufficiently established to embark on building improvements incorporating architectural rather than functional features?

Track Development

The earliest inter-city track, using wrought iron fish-bellied rails resting in chairs fitted to stone blocks, had evolved from the best practice of the colliery wagonways and other coal-carrying public railways. It was soon clear however that the higher speeds and dynamic forces of inter-urban passenger and goods operations would require a heavier duty track that was robust enough to withstand a regular service. Several initiatives were taken to improve track design, but little has been written to explain their objectives and performance[19], and there is much more to be learned about track development throughout the first thirty years or so of main line operation. Was the cost of installation and maintenance the primary consideration for railway companies, or was improvement of ride quality the principle objective to encourage greater patronage and profitability?

The earliest track adopted stone sleepers, but these were labour-intensive to quarry, dress, transport and lay. Wooden sleepers were at first used across embankments to aid stability of the new earthworks, but were soon adopted as the norm for main line track. What were the cost comparisons between sleeper types, and was the move to wooden sleepers driven by cost alone or were there other factors which engineers learned from each other by experience? Wooden sleepers in Britain were 'kyanised' using a chemical formula supposed to preserve the timber from deterioration. How effective was this formula and was it taken up in Continental Europe and North America as well or were other preservatives developed?

There were wide variations of rail types from the basic 'iron strap and wood stringer' rails of early American portage railroads to the Locke 'dumb-bell', Brunel 'bridge' rails and 'Barlow' rails of early British main lines. To what extent was there professional

[18] John Britton, 'Historical and Descriptive Accounts… etc…of the London and Birmingham Railway', in John C. Bourne, *Drawings of the London and Birmingham Railway (*London, 1839, re-printed in facsimile, Newton Abbot, 1970), pp.13/14.

[19] The last general review of early track development was C.E. Lee, *The Evolution of Permanent Way* (London, 1937, revised and enlarged, London, 1943). Recent books have included short sections on permanent way, including Mike Chrimes, 'Permanent Way', in 'London and Birmingham' chapter, in Bailey (2003), pp.54-56; Derrick Beckett, *Brunel's Britain* (Newton Abbot, 1980), pp.40-44.

exchange of ideas and trial results between engineers, particularly those in different countries? What comparisons were made regarding unit rail weights for different types of operation, and their costs of rolling, installation and maintenance? How did the Locke, Bridge and Barlow rails compare, both for first cost and costs of maintenance? Did the engineering profession as a whole initiate trial installations of different track types or was the initiative with individual engineers seeking the best track for their clients?

What were the effects of British industrialists improving iron rolling techniques on output and price of rails? What were the effects of trade tariffs on the export of rails from British ironworks to Continental Europe and North America? Did these tariffs encourage the setting up of rail rolling firms in these respective regions and how long did it take for these industries to develop?

Early references and illustrations of track bases reveal the use of waste material from a variety of sources. How effective was the use of waste material, both from a drainage point of view and as track base for both stone and timber sleepers? Under what circumstances did the use of stone chippings begin to be recognised as a material better suited as a track base?

Locomotive design and manufacturing development

The first locomotives of the main line era were developed in a remarkably short time to fulfil the requirements of inter-city passenger and goods operations[20]. In spite of their initial reliability problems, the use of locomotives ensured that these operations were profitable. This in turn encouraged many other investors to pursue further railway schemes based on locomotive operation. The rapid expansion of the railway network was accompanied by major improvements to locomotive design that provided increased services, higher speeds to meet perceived demand, and heavier loads to increase the profitably of operations.

A recent academic study has laid the foundation for understanding Britain's independent locomotive industry throughout the 19th century.[21] However, there is considerable scope for developing knowledge about the industry and the extent and manner in which manufacturers responded to the rapidly growing demands of railways in Britain and overseas.

The number of locomotive manufacturers in Britain rose from just one in 1830 to 34 by the end of the decade. There have been several comprehensive histories of individual manufacturing firms, usually focussing on the locomotives that were produced rather than on business histories that explore their managerial processes[22]. Most of the firms were manufacturers of other machines that diversified

[20] Michael Bailey, 'The Mechanical Business', in Bailey (2003), pp.163-210.
[21] Michael R. Bailey, *Decision-Making Processes in the Manufacturing Sector: The Independent Locomotive Industry in the 19th Century*, unpublished DPhil Thesis, University of York, Institute of Railway Studies, 1999.
[22] For example, J.G.H. Warren, *A Century of Locomotive Building by Robert Stephenson & Co. 1823-1923* (Newcastle Upon Tyne, 1923).

into locomotive building, but how was this undertaken and how did they achieve the skills to start up and develop locomotive design and manufacture?

The basic main line locomotive design was achieved with the prototype *Planet* of 1830, but many problems, largely relating to material reliability, had to be resolved in the earliest years of operation. How were improvements in component designs and development of appropriate materials achieved? To what extent were improvements protected by their inventors through patenting? Was there significant movement of personnel between different manufacturers to accelerate the transfer of design and manufacturing knowledge between firms?

The implementation of new machine tools radically changed manufacturing processes from the 1830s[23]. Was their introduction to overcome a shortage in skilled personnel as locomotive demand increased, or was the reduction in manufacturing cost the principle reason? How did firms with a high investment in machine tools, and employing semi-skilled staff, compare with firms maintaining traditional craft practices for locomotive production? What reliance was there on component sub-contracting?

The extraordinary demand for new locomotives during the 1840s 'mania' years in Britain saw huge delivery delays, encouraging railway companies to develop their own construction facilities. Workshops such as Crewe and Swindon quickly achieved competence in designing and building locomotives, thus beginning a strong tradition of railway-owned design and building practices that perpetuated to the late 20th century[24]. What were the long-term incentives for the railway companies to provide their own motive power and why was the industry so prolific in Britain but abnormal in Continental Europe and in North America?

The earliest railways in Continental Europe were dependent upon British manufacturers for their initial fleets of locomotives. However, from the mid-1830s locomotive manufacturing got under way in France and Belgium, albeit with British industrialists and engineers anticipating the needs of the growing network of lines[25]. Was this achieved by training Belgian and French personnel in Britain or attracting British skills to the Continent? After the European political upheavals of the 1840s, locomotive manufacturing began in earnest, particularly in the German states. Were there political and economic issues that brought this about, such as import tariffs, or was it simply growing technical competence that made this possible?

The immediate interest in railway development in the United States from 1830 saw a demand for locomotives that was different from those developed for use in Britain and Continental Europe. British manufacturers were slow to adapt their designs to the very different type of track and terrain in North America, and a new locomotive

[23] Rev. Dr. Richard L. Hills, *Life and Inventions of Richard Roberts 1789-1864* (Ashbourne, 2002).
[24] M.W. Kirby, 'Technological Innovation and Structural Division in the U.K. Locomotive Industry', in Colin Holmes and Alan Booth (eds.), *Economy and Society: European Industrialisation and Its Consequences* &c (Leicester, 1991), pp.24-42. Diane K. Drummond, *Crewe – Railway Town, Company and People, 1840-1914* (Aldershot, 1995).
[25] D.H. Stuart and Brian Reed, 'The Crewe Type', in Brian Reed (ed.), *Locomotives in Profile*, Volume 2 (Windsor, 1972). No history of the Cockerill Company of Liege in Belgium has yet been written.

building industry quickly developed in the United States[26]. What were the reasons for this lack of awareness by British industrialists and how did manufacturers in the United States obtain the skills that enabled them to start manufacturing their own locomotives and sustain the rapidly growing demand? To what extent were import taxes influential on the start-up of the American industry?

Locomotive design developed rapidly to become considerably more capable and efficient in the 1840s and 1850s[27]. How was such rapid progress made – through empirical understanding or theoretical comprehension of dynamic forces and material strengths? To what extent did key design and manufacturing personnel transfer between firms and countries to make possible a 'technology transfer' of skills and experience to expand the industry?

With the locomotive industry diversified amongst British, European and American manufacturers, how did design and construction methods evolve in the three regions? Was this achieved through collaboration or independent development? What were the influences on the design and manufacturing processes and what skills transfer was necessary to achieve these processes?

Rolling Stock design and manufacture

Demand for passenger travel was unexpectedly high from the commencement of main line operations in 1830, and grew rapidly thereafter[28]. By 1860, after just 30 years of railway operation, the number of passenger-journeys annually in Britain had reached 163 million, excluding season ticket journeys[29]. The construction of passenger carriages to meet this demand therefore required a major new industry, for the development and construction of both chassis and coach-bodies. In the early 1830s some local road coach building firms diversified into railway carriage manufacture, but by the 1840s consolidation was taking place to form a new industry of specialist manufacturers fulfilling the coaching needs of both British and overseas railway markets.

Although there have been occasional histories relating to the carriage building industry[30], there has been no comprehensive research undertaken into the subject. Hence there are many questions surrounding the design and construction of both chassis and bodies that are available for research. To what extent did established road coach manufacturers diversify into rail coach body manufacturers, to provide the requisite skills for the manufacture of first-class vehicles? Was the provision of chassis dependent upon general manufacturing firms diversifying into a new market, or did the railways themselves start up in manufacturing chassis to receive coach

[26] John K. Brown, *The Baldwin Locomotive Works 1831-1915* (Baltimore, 1995). John H. White Jr., *A History of the American Locomotive – Its Development: 1830-1880* (Baltimore, 1968, re-published New York), 1979.
[27] E.L. Ahrons, *The British Steam Railway Locomotive 1825 to 1925* (London, 1927); Zerah Colburn, *Locomotive Engineering and the Mechanism of Railways*, 2 vols. (London, 1871).
[28] R.H.G. Thomas, *The Liverpool and Manchester Railway* (London, 1980), pp.186 *et seq*.
[29] Board of Trade statistics. See for example, J. Holt Schooling, 'Lessons from Railway Statistics', in *The Railway Magazine,* Vol. XII, 1903, pp.424-431.
[30] C. Hamilton Ellis, *Railway Carriages in the British Isles, from 1830 to 1914* (London, 1965).

bodies, or again did new manufacturers start up pursuing the new market opportunity?

What were the origins of the tradesmen who were attracted into the new industry, and how did production facilities develop to keep up with the demands for new carriages? What materials were used in the construction of chassis, and how did they develop more robust frames to withstand the dynamic forces of everyday operation? How did the chassis builders develop vertical and horizontal springing, for the comfort and safety of passengers? What emphasis was placed on braking and other safety issues?

The standard of accommodation in carriage bodies reflected the social practices of the day. First class carriages were upholstered, whilst second and later third class carriages had only basic facilities for the 'lower' classes. To what extent did the accommodation represent a continuation of road coach practice, and how were designs later influenced by the conflicting aims of profits for the railway companies and national moves towards social improvements through better accommodation in second and third class carriages?

Goods traffic conveyed by rail similarly increased significantly in the first 30 years of main line rail operation. By 1860, some 90 million tons of goods and mineral traffic were being conveyed annually in the U.K.[31] Thousands of wagons were required to fulfil the growing demand. Wagon hoppers for the conveyance of minerals had been in use on early railway systems for many years. However, different forms of wagon bodies to carry a diverse spread of traffic were required for the conveyance of goods along main line rail routes. These included general crates, barrels and bales in simple flat or low-sided open wagons, and high-sided bodies for livestock[32].

Did the hopper manufacturers diversify into making other types of goods wagons or did new firms start up to meet the new demand? Where did the tradesmen with the knowledge of rail vehicle design originate? At what point did rolling stock manufacturers branch out from being multi-centred localised activities to form consolidated regional industries manufacturing both chassis and bodies serving the requirements of both Britain's railways and export markets? To what extent did the railways themselves engage in the production of vehicles and what were the advantages over contracted-out production?

In what way did the rolling stock industries of Continental Europe and North America develop differently from those in Britain, and to what extent did national tariffs influence the evolution of these industries? From where was there a transfer of skills to allow the start up of new rolling stock manufacturers? The North American railroads developed much larger vehicles than those employed in Europe, employing swivelling bogie wheel-sets. What were the influences that encouraged this innovation? Was it simply the poor track of the early lines, or were there other, economic, reasons?

[31] Board of Trade statistics. See Schooling, *op cit*.
[32] Thomas, *op cit*, pp.183-5.

Railway Safety

Accidents on early main line railways were all too frequent as companies gained experience with new operating procedures, and the dynamic forces on track, locomotives and rolling stock[33]. How were safety issues first considered by railway companies, and what measures did they take to deal with them? In what ways did governments first consider issues related to railway safety, and what were the circumstances that led to legislation requiring safety measures to be implemented in Britain, other European countries and in North America? Britain introduced a railway office, within its Board of Trade Department, to oversee safety issues and requiring the submission of annual returns on safety matters. Did governments in other countries follow Britain's lead in establishing departments with safety responsibilities?

The availability of the electric telegraph played an important part in the safe operation of railways from its introduction in 1840, particularly with the introduction of single line operations[34]. What were the technical developments that made possible its introduction and how was the basic system developed to meet the demanding requirements for railway safety?

The increase in traffic led to the need for 'block' signalling regulations on some early railways, in turn giving rise to the need for mechanical signalling to supplement the services of the earliest 'policemen'. How was the engineering of mechanical interlocking developed, and did manufacturers establish themselves to promote proprietary signalling systems or to develop the particular requirements of individual railway companies? Was there co-operation between railway companies in the development of mechanical signalling, and under what circumstances did this arise? Did national signalling systems evolve in each country, and to what extent did Britain export its signalling expertise to other countries?

The first main line trains were braked by shutting off steam and coasting to a halt, employing also counter-pressure braking and the use of screw-down brakes on tenders and brake carriages. Very little has been written about the braking of early railway trains. As train loads and speeds increased, a number of schemes were promoted, but standardisation of systems remained elusive until the third quarter of the nineteenth century. Why did it prove difficult at first to find acceptable systems of braking? Were there adequate attempts by governments to encourage, or even force, railway companies to introduce braking systems?

[33] R. Ritchie, *Railways: Their Rise, Progress and Construction, with Remarks on Railway Accidents and Proposals for Their Prevention* (London, 1846).
[34] J. Kieve, *The Electric Telegraph: A Social and Economic History* (Newton Abbot, 1973).