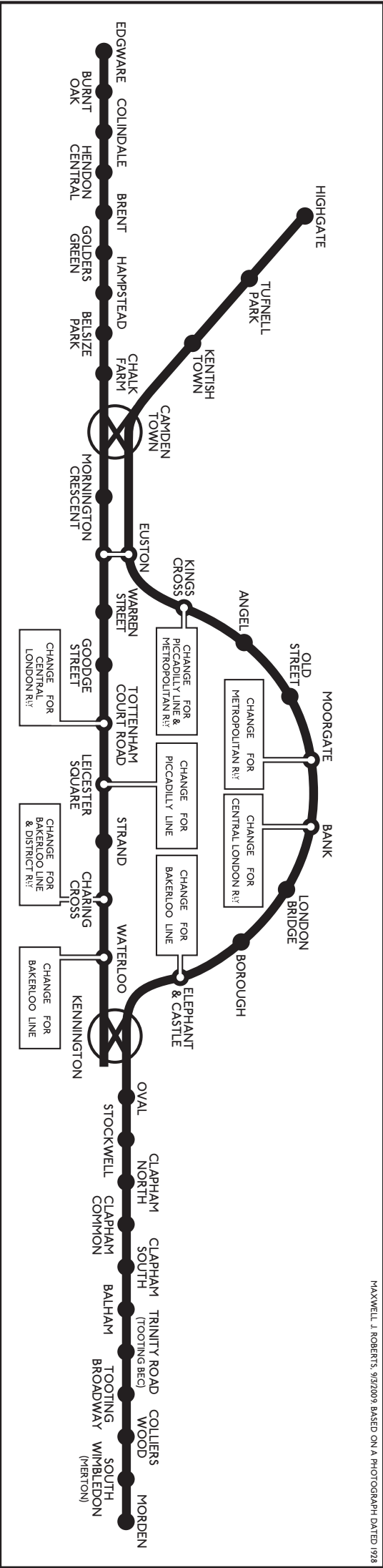


Henry Beck Rules, not OK?

Breaking the Rules of Diagrammatic Map Design

Maxwell J. Roberts
Department of Psychology
University of Essex
03/08/2009

OBSOLETE MANUSCRIPT: Please DO NOT cite without permission: research@tubemapcentral.com

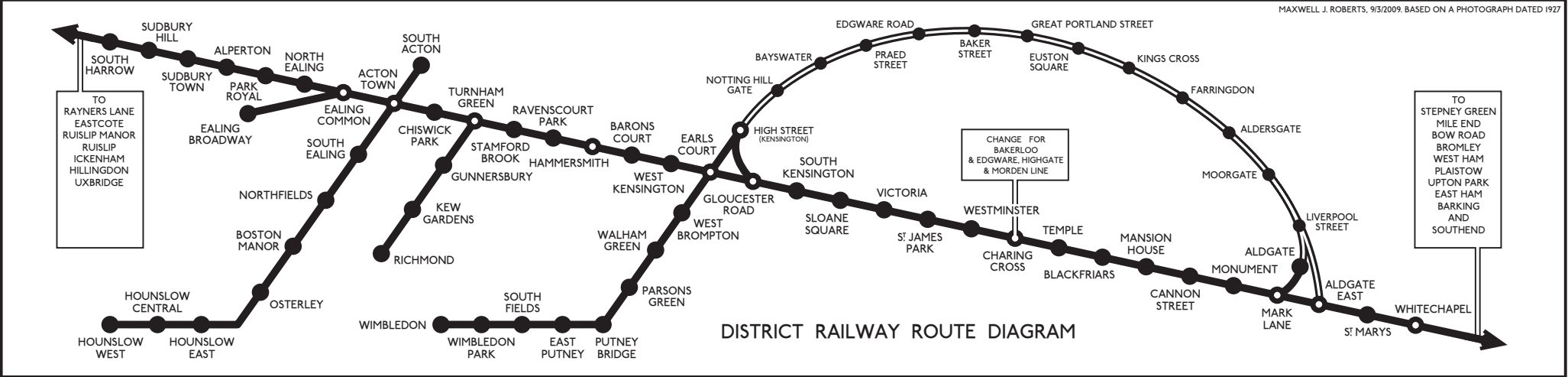


In 1931, Henry Beck revolutionised map design by creating the first diagrammatic map of the London Underground. Inspired by electrical circuit diagrams, his techniques have been widely imitated, their adoption transforming the clarity of transport maps worldwide.

This is the story that many people believe. The only problem is that some of it is false. The importance of electrical circuit diagrams for Beck's thinking has almost reached the status of an 'urban myth'. In reality, as an Underground commuter, for many years Beck was surrounded by schematics of individual Underground lines. His own design was firmly-based on already-existing techniques, the main difference was his ambition in taking the next step beyond *individual* line maps, in effect combining them to show the *entire* Underground network, schematically for the first time [4, 15].

The reason why it is important to correct this misconception is that it diverts attention away from Beck's real achievement. Bad schematic maps (whether of London's Underground, or any complex network), which lack clarity, distort geography beyond people's comfort zones, or are just downright ugly, are very easy to design. In contrast, Beck's early designs quickly gravitated towards a clear elegant simplicity. For any network, the very best maps do not just make journey planning easier. Their apparent simplicity will imply that travel will be effortless, and an attractive design will engage people, encouraging them to make full use of it. Beck's early success ensured both the rapid acceptance of his designs by the travelling public, and the persistence with these techniques by London Transport. Rather than the invention of a new cartography, it is Beck's aesthetic judgement that should be celebrated. Failure to appreciate this deflects from the important issues of why his designs were simple and attractive, how this helps people, and from this, how to design the best possible schematic map for any given network.

The earliest known car line diagrams from the Underground were first used on the District Line in 1908. The pair shown here date from the late 1920s and depict the two most complex lines operated by the Underground group of companies, the District and the Northern. Designed to fit into wide, narrow spaces, geographical accuracy would be impossible to attain, and schematic maps became commonplace. Living near a Northern Line station, but working near a District Line one, Beck would have seen designs such as these every day that he travelled to and from work. The Northern Line map is shown on its side here to emphasise Beck's probable flash of insight: superimposing one on the other would mean that much of the Underground network had been mapped.



One notable feature of Beck’s work, which has been adopted throughout the world, is the particular set of design rules that he used. Here I am going to discuss whether these really should be the first choice of every designer faced with the task of creating a map of a transport network. The problem, we will see, is that as networks get more and more complex, in certain circumstances

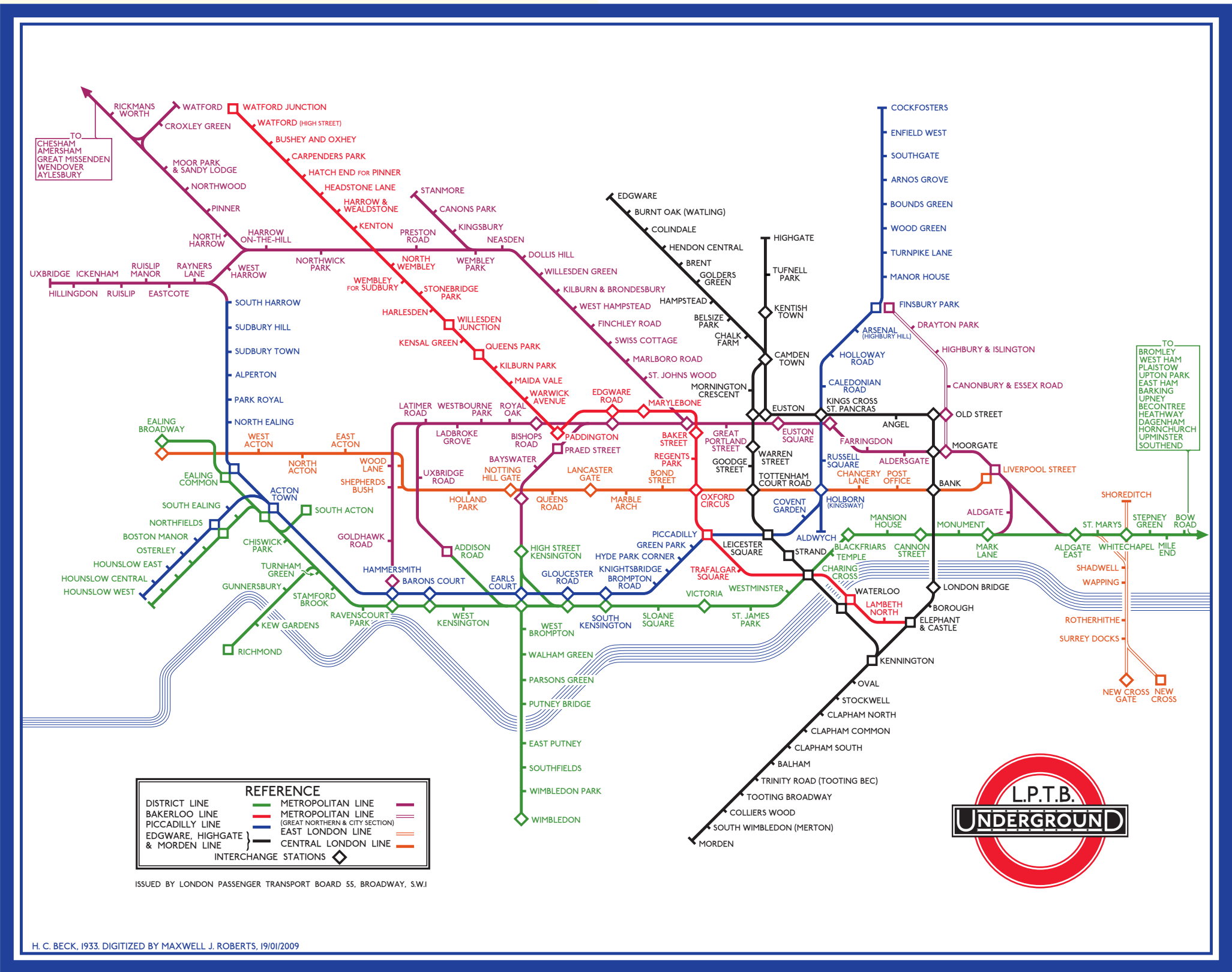
the clarity and attractiveness of maps using these rules can break down. Whether this is an inevitable problem that passengers will simply have to learn to live with depends on whether it is possible that by breaking the rules intelligently, designers can restore usability and elegance to such maps.

Henry Beck’s rules, and why they were well-suited to London in 1933

What are Beck’s rules? We have to distinguish between the basics underlying all of his designs, and cosmetic embellishment. The current London Underground map has symbols and conventions that were never used during Beck’s period of creating maps for London Transport (designs bearing his name were issued from 1933 to 1960). Not only this, but Beck’s own maps also differed considerably in these superficial aspects during his career, especially for the difficult problem of how best to show interchanges between lines [5, 15]. The crucial features of Beck’s rules are as follows:

One of Beck’s most celebrated designs is also one of his earliest. The 1933 quad royal station poster embodies his much-admired flowing pre-Second World War style. Interchange diamonds provide an art deco flourish, and although predating the map by more than a decade, Edward Johnston’s sans serif typeface and the roundel complement the style perfectly.

The image shown here, like many other illustrations in this article, is a digitisation of the original map, by the author, using a vector graphics package, but keeping as faithful as possible to the intended design. This enables the highest possible image quality, undamaged by the passage of time and free from the vagaries of earlier print technology.



1) Lines must be vertical, horizontal, or diagonal. Diagonal lines must be at 45°.

2) Curves must be tightly radiused.

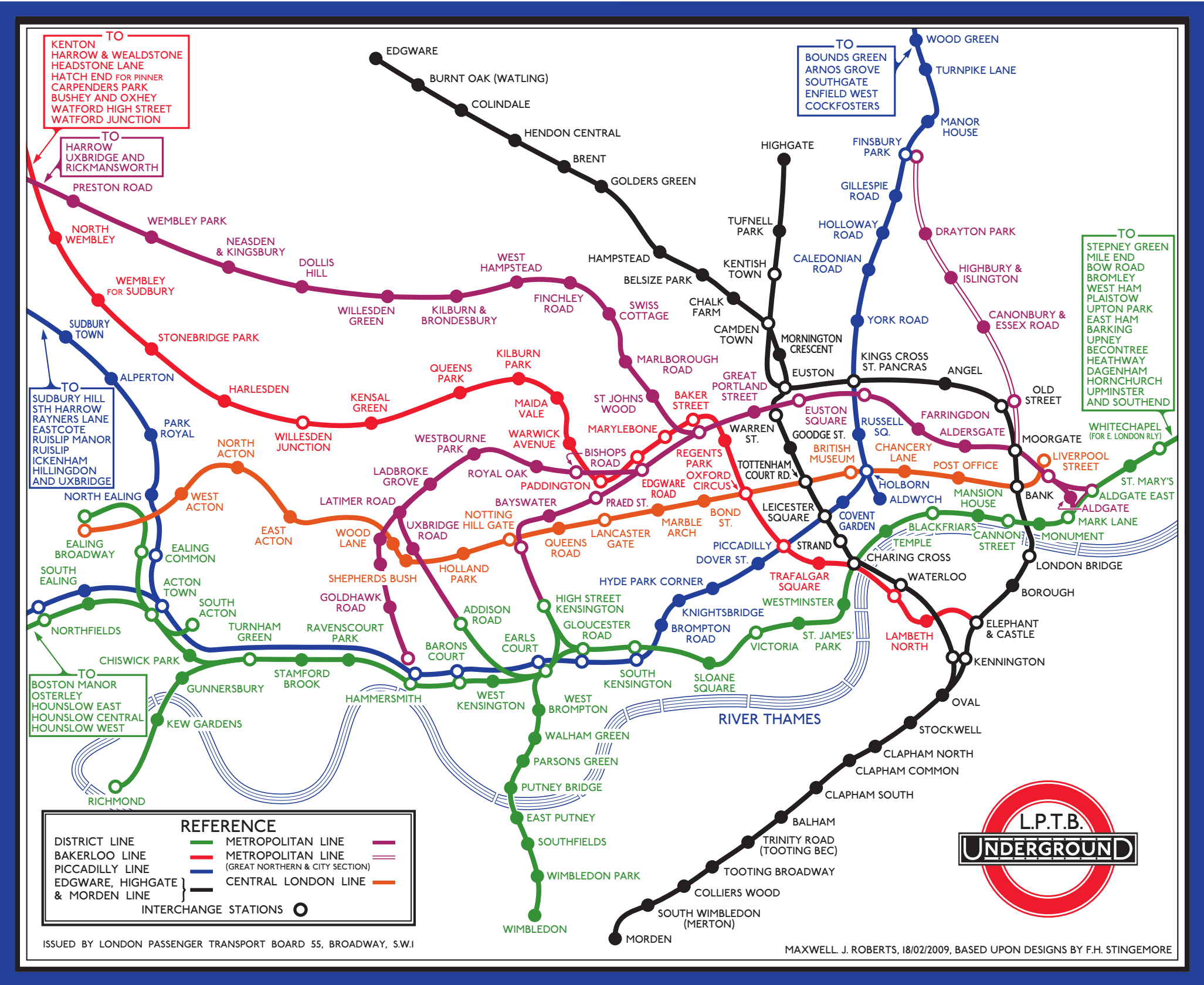
3) Stations should be on straight-line segments (this is not absolute, but is never broken lightly).

These rules have been followed by almost every diagrammatic London Underground map designed by Beck and his successors. Indeed, for many people, these rules are synonymous with the entire concept of a diagrammatic map, although a precise definition of what exactly constitutes one is difficult to identify [4, p. 13; 15, p. 6]. More strongly, to some people, these rules equate to a mapping gold standard: adhering to these, and implementing them competently, will produce the best possible representation of a transport network, a sentiment detectable in the writing of many commentators [e.g., 13, p. 39] and researchers. For example, in the guise of *octolinearity* (at any given point, only

a maximum of eight directions is possible), it has been suggested that this rule set forms a “hard constraint” which must absolutely be obeyed in order to produce a “nice drawing” [21].

It is very difficult to find direct evidence for the gold-standard view. Indeed, many operators from around the world have experimented with diagrammatic maps, and given up (e.g., the New York Subway, see Box 1; the BART network of San Francisco). Even so, it is the elegance and flow to Beck’s work that helped to make him famous, particularly for his early designs, which are amongst the most highly regarded [e.g., 5, p. 21], and excellent candidates for the title of ‘design classic’

Beck’s predecessor for pocket maps, designed by Fred Stingemore. This digitized version is based upon his last design of 1932. Note the cramped centre and the indecisiveness of the lines. Knowing relative station locations might be useful, but the twists and turns of the lines between stations were irrelevant to planning a journey.



or ‘design icon’ [1, 2]. This certainly might imply that these rules could form a good starting point for any network. However, we should be cautious before inferring that following these rules is *necessary* in order to produce the best design possible (it is certainly not *sufficient*, as we will see). In many ways the London Underground of the 1930s lent itself ideally to being depicted using Beck’s rules.

First, the network had three properties that demanded unusual levels of geographical distortion, paving the way towards schematisation:

1) Far reaching suburban destinations (e.g., Watford Junction, Hounslow, and Morden).

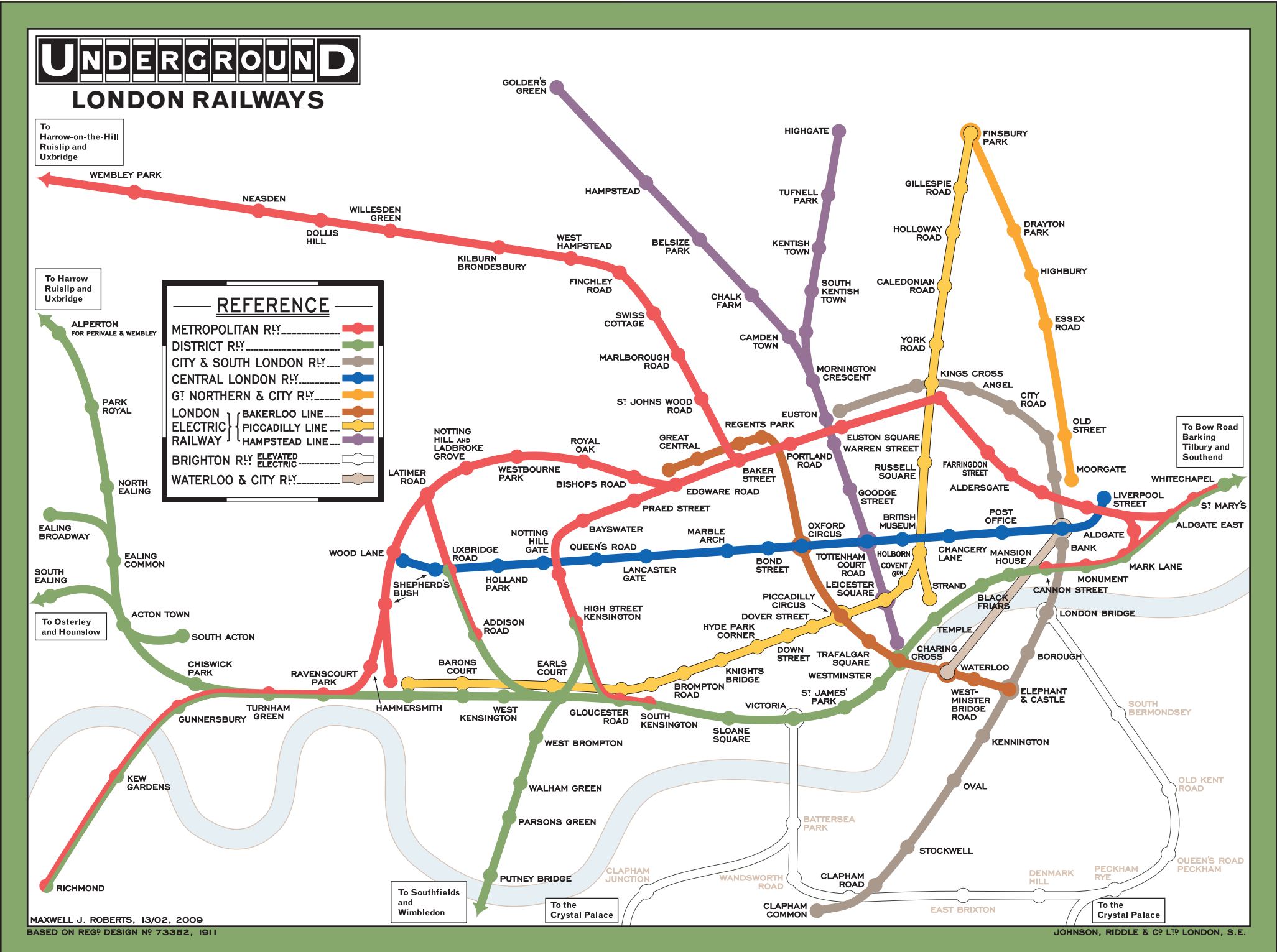
2) Widely-spaced stations in the suburbs, closely-spaced stations in the centre.

The network therefore could not be meaningfully shown to scale. The result would have been a large, unwieldy map, much of it blank, but even then the centre would have been cramped and practically unreadable.

3) Meandering lines which twisted and turned, following the paths of ancient streets (so as to avoid risking compensation claims for subsidence to buildings above), so that the orientation of a line at any particular point was not necessarily a direct reflection of its overall trajectory.

Early attempts to cope with the difficulties of showing the London Underground network included expansion of the centre, removal of street and other details, and simplifying sections of line. This map, published in 1911, was a significant step in the evolution of schematic network maps. It straightened the lines considerably, but retained street details. I have digitised this design without them, making the route simplification clear. The later Stingemore map seems positively reactionary in comparison.

So, with insufficient geographical distortion, the resulting map would inevitably be difficult to read, with a compressed and complicated centre, and rather empty-looking suburbs. Many designers before Beck had addressed these issues out of necessity, but in the process they did not create diagrammatic maps as we understand them in the process [8, 15].



Second, once Beck had taken a step away from geographical fidelity, it turned out that the resulting diagrammatic map had some properties that made it useful not only for showing the Underground network, but also for defining London itself.

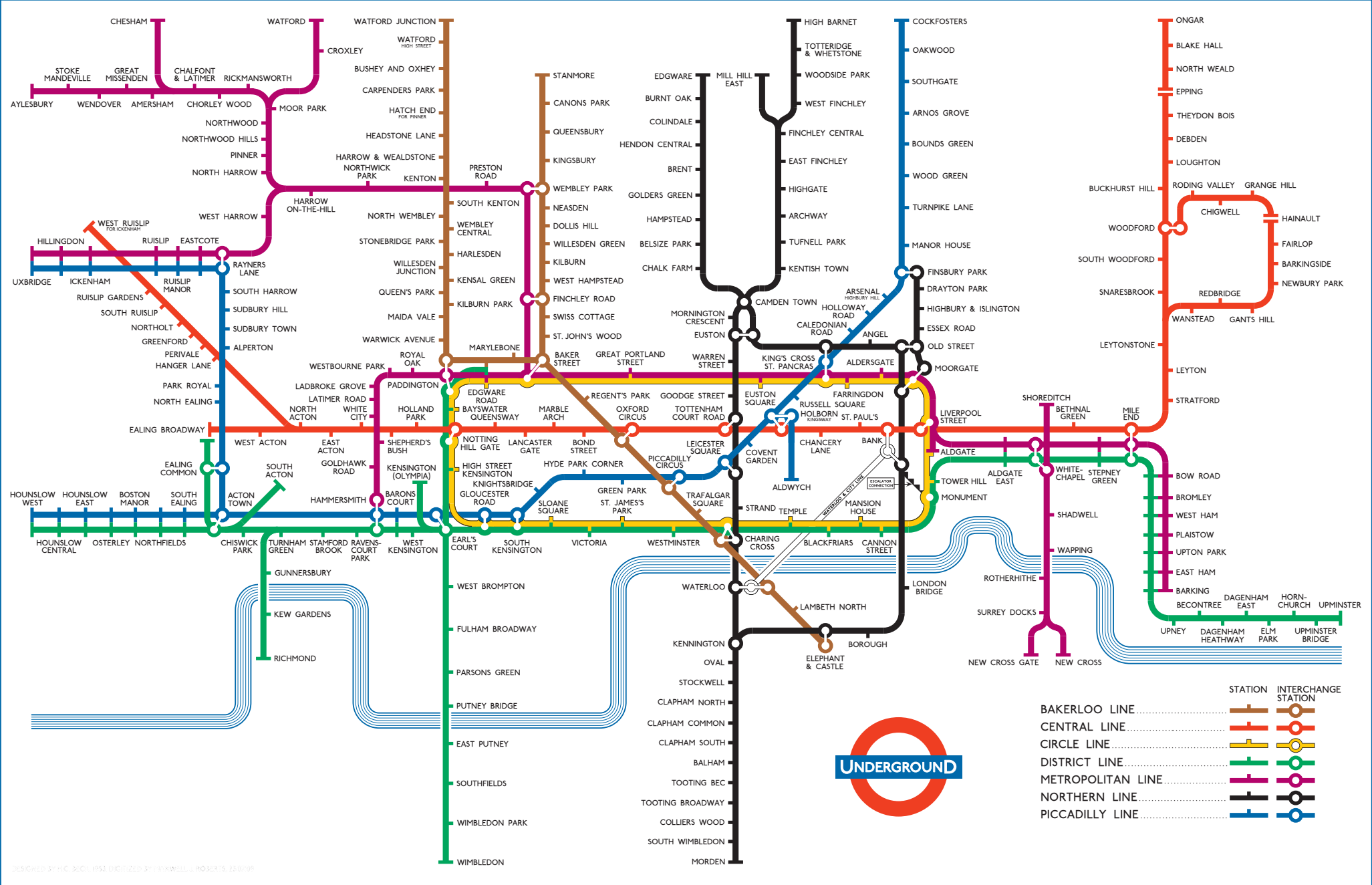
1) There was an older system of orbital lines that skirted the Central London. Once their loop was regularised and its meanders removed, it highlighted London’s Central Business Districts. As the shape of the loop became more and more regular (and eventually, in 1949, coloured yellow), it performed this task even more effectively.

2) This loop also highlighted the middle sections of the newer deep-level tube lines which crossed Central London, following some of its most important streets.

In later years, the Circle Line was given its own identity (yellow in 1949) making it even more effective at defining Central London. In an attempt to regularise its shape, Beck’s final design (1954) depicted it as a perfect rectangle, but for many people this version was too stylised, too abstract, and too distorting. Subsequent official Underground maps have never distorted London to the same degree. However, note the simplicity of the routes in Central London, with just three kinks inside the Circle Line.

In short, diagrammatising the network didn’t just make it clearer, it also created a natural set of well-defined focal points, which corresponded with people’s actual travel needs. Not only this, but for early designs, the level of geographical distortion was relatively low. For London experts, there would be little conflict with their expectations, and for novices, the designs assisted them in making sense of the city, defining it and enhancing their perception of it, to an extent that no other map has ever achieved, or perhaps could achieve, anywhere else [20, Box 1, Box 2].

But all good things come to an end. The size of the Underground network has increased considerably since 1933. Indeed, Beck’s initial maps only showed two-thirds of the extent of London, the eastern end of the District Line was summarised in a text box on the right-hand side of the map. Had Beck been strategically waiting to submit his design at the ideal moment, the early 1930s would have been the best time possible. The network had developed to the point at which the Underground company’s more conservative network maps were being put in considerable difficulty, but had not yet reached the point at which Beck, using his design rules, might likewise have been hard-pressed to reach an attractive usable solution.



The psychology of information interpretation: Why diagrammatic maps can make life easier

Even if a city lacks the features that made the London Underground well-suited to a schematic in the 1930s, a map following Beck’s rules can still be easier to make sense of than a geographical one. In order to understand why, it is necessary to pause and reflect on the psychology of interpreting information and drawing conclusions (such as when using a map to decide which is the best route to take). In brief, people seek to simplify the world. A simple world is predictable and easy to remember. Beliefs, prejudices, stereotypes, and rules of thumb are all examples of simplification, even though they are not always accurate, and may even be repugnant. They allow people to function without expending too much mental effort. It seems safe to infer that the benefits of this behaviour must exceed its costs, otherwise evolution would not have programmed our brains to do this so readily. More sophisticated, people can attempt to understand the underlying principles and structure of the world, basing their decisions on these: things which appear to be complex are often simpler than they look (in other words, reductionism). Of course, if we try to look for these details ourselves, we might miss them, or make mistakes, which is why sometimes we need help to identify them.

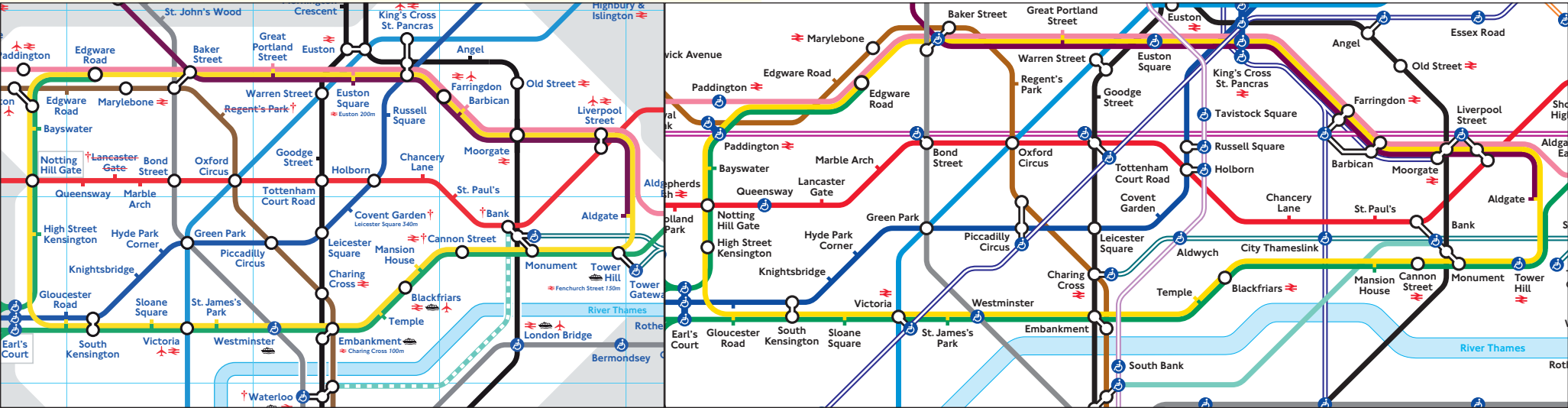
This is where Henry Beck came in. Previous versions of the Underground map were chaotic. Detailing every twist and turn on the network map hid its underlying structure, masking its simplicity, making it more complicated to interpret, harder to use, and difficult to remember [15, p. 106]. Beck

cast away these irrelevant details. He presented the routes as simple straight lines, minimising kinks, maintaining their interchanges, and making their overall trajectories – northbound, eastbound, westbound, southbound – easy to identify. He was effectively cutting out the first stage of map interpretation. Instead of the passengers having mentally to organise the map and identify the underlying structure of the network for themselves, Beck presented them with a ready-prepared version. By performing this mental effort on their behalf, passengers had more mental capacity available for planning and remembering their routes. Beck did the hard work for us, but crucially, the hard work was worth doing. For this particular system, by applying his set of rules, it was possible to produce a network diagram which was genuinely simple, well-organised, and had a memorable underlying structure.

When Henry Beck’s rules break down, and why

Time and time again, psychologists have shown that the more information people are given to think about, the longer they will take to make a decision, and the more likely that they will make errors. Fundamentally, when considering the ease of interpreting a map, we need to consider the configuration of the lines. The easiest trajectory for the human eye to follow is a straight line, which is why Beck and successive designers have tried to straighten routes on the Underground map as much as possible. But what happens if we add a bend to a line? The path is disrupted by this new piece of information, and the eye must find and adapt to the new route. What if the line bends again? We must adapt again. And again? And again? With every kink, the map becomes harder and harder to interpret because it contains more and more information. The overall trajectories of the lines become difficult to discern

Moving forward (central area from 2006) and into the future (projected network for 2025) we can see that as more and more lines are added to the map, so the simplicity and appeal that led to its iconic status have become eroded.



and less memorable, and the fundamental structure of the network, previously buried by complex twists and turns in geographical reality, is now at risk of becoming buried under complex zig-zags instead.

Psychologists have known about the problems caused by information quantity for many years, and capitalise on these when, for example, they design intelligence test items [9, 17]. The ones which are hardest for people to solve are those where the hidden answers are buried by detail, with complicated-appearing shapes hiding what are nonetheless relatively simple rules. Put simply, a map can be seen as an intelligence test, with the user having to identify the underlying patterns and plan the best journey from the information [10]. A complicated map is a difficult intelligence test, with all the negative consequences implied for today's ethos of accessibility and inclusion.

We therefore need to take another look at Beck's rules for designing maps. Anyone who advocates them *must* implicitly believe that there will be circumstances in which a map will break down and become unusable. The key here is the criterion of simplicity, defined and implemented by trying to reduce a map to a set of straightest-possible line-trajectories but keeping geographical distortion under control [18, 19]. We can imagine a dialogue something like this:

Beck Advocate: *"A straight line is the easiest trajectory for the eye to follow. Meandering curves are harder to follow, and to design the perfect map we must eliminate them."*

Beck Sceptic: *"But a kink is a very sharp curve, and is surely more disruptive to the eye than a gentle one. If all we do by straightening the lines is shunt their curvature into a large number of kinks, we haven't solved the problem at all, we've just moved it around. All that jerkiness might even make matters worse."*

At this point, we should turn our attention back to the London Underground map, and consider the possibility that its design is not as attractive or usable as past versions [15, p. 104]. Partly, this is for reasons irrelevant to Beck's rules. London Underground's well-intentioned attempts to help passengers navigate the system have cluttered the map with more and more information. All those dashed lines, warning daggers, zonal boundaries, interchange symbols (boats, trains, trams, and

planes, but not buses just yet), and now wheelchairs, add to the quantity of information to think about, and are therefore just as likely to confuse as to help, especially in cases where the details have not been applied clearly, thoughtfully or consistently [7]. Adding too many symbols and caveats to a map therefore makes it harder to use because this increases the *cognitive load*. Worse still, as more information is added to the map, this also raises the cognitive load for the designer, increasing the likelihood that erroneous or ambiguous information will be added. A large *quantity* of poor *quality* information raises the cognitive load for the user considerably. It is not enough to presume that people can screen out all these extra details, so that each person will think about only the precise information that is important for him or her, because, as psychologists know, people generally cannot do this. Only the most expert of system users will easily be able to filter irrelevant from relevant information. The original message conveyed by Beck's design – that this simple, easy to use network can take you to wherever you need to go, quickly and easily – is today at risk of being drowned out by *information pollution*. If the extra details really are necessary, we have an impossible problem. A good map can't fix a bad network [6].

Putting to one side the cognitive issues associated with adding supplementary information, inevitably, as more and more lines and branches are added to a network, the complexity of any schematic will increase and its usability will decrease. Since the year when Beck was forced to retire, the additions to the London Underground map include the Jubilee Line, Victoria Line, various extensions to reach Heathrow Airport, the Docklands Light Railway, and the London Overground. Stubbornly remaining at its original 1930s size, one consequence of this is that the Underground map has smaller lettering and thinner lines than ever before, but worse still, where Beck transformed meandering curves into simple bold straight memorable lines, the effect is now lost. Lines zig-zag uncomfortably across the page. Whereas in 1960 there were just three kinks inside the Circle Line, today there are 14.

"But surely, Beck's rules are the best rules?" asserts the Beck Advocate. *"They are the simplest, purest way of presenting this information, and they must be the best because designers around the world have adopted them. The*

Underground map might be complex, but, just think how difficult it would be to perceive and understand if Beck's rules were not used."

To reply to this suggestion, we need to think about why designers so often choose Beck's rules. We also need to think about what other rules might be available, and how they might be used or misused. We also need to look at some actual examples of experimentation, not casually thrown together, but created with at least some of the care and thought that Beck himself put into his own work. It is important to distinguish between: (1) design failings *within* (or *despite*) a set of rules, where a less-than-competent designer fails to optimise a map, resulting in many kinks and other poor design features; versus (2) design failings *because of* a set of rules, where the rules themselves are a poor match for the properties of a network, so that no matter what the skills of the designer, a difficult-to-use map will result. Even the best set of rules

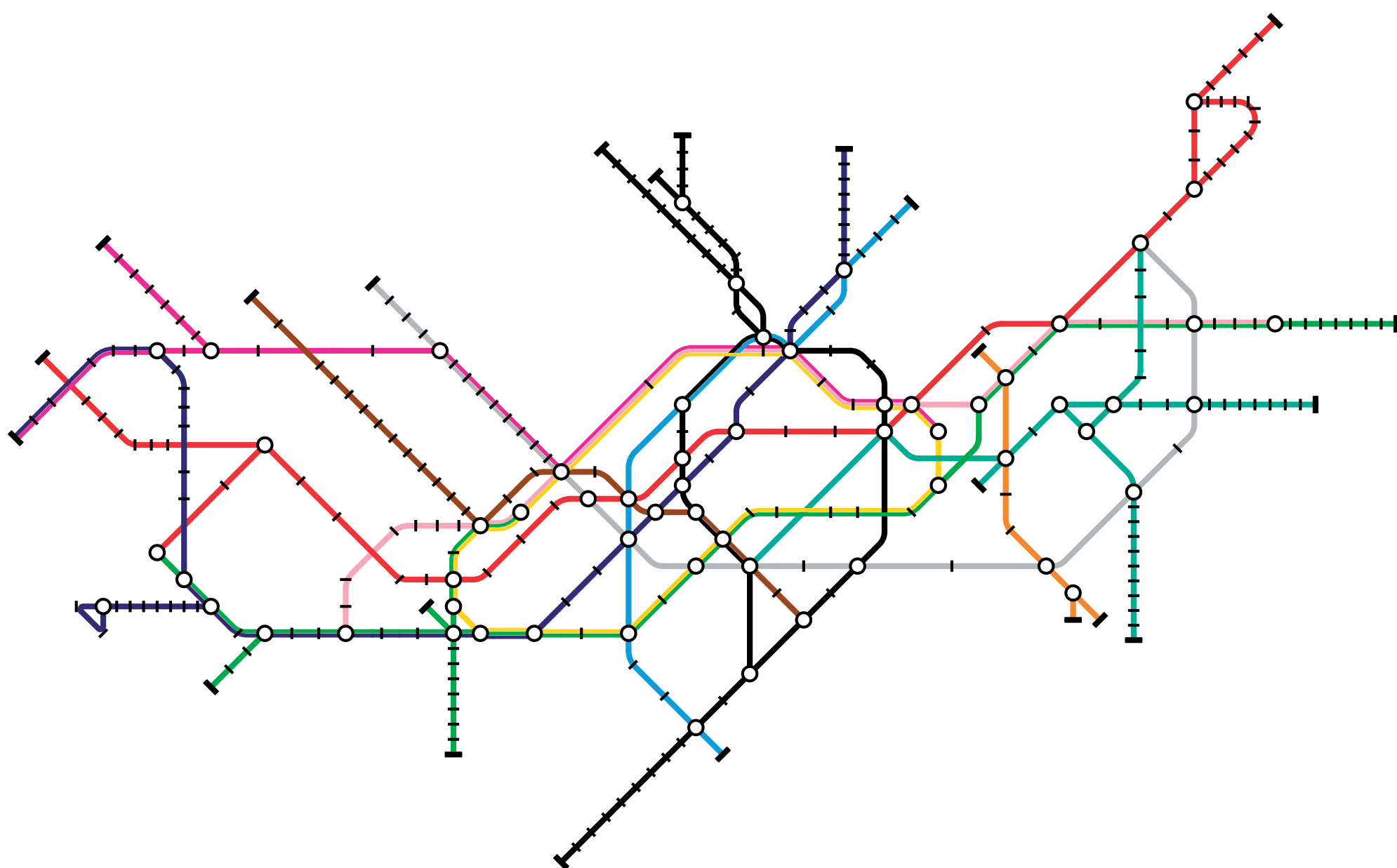
cannot guarantee the design of a good clear map, but a poor choice of them will make one almost an impossibility.

Many of the following examples will use the London Underground as a case study. It is a suitably complex and disorganised system, and only by seeing the *same* network mapped in different ways can we appreciate the strengths and weaknesses of various approaches.

Choosing the rules

For any designer faced with the need to create a network map from scratch, Beck's rules seem to be a perfectly good starting point. Taking a set of interconnected meandering routes, and simplifying them in this way, has produced a huge number of perfectly serviceable designs around the world. However, if Beck's rules are associated with any aesthetic or usability gold standard, then this cannot be a natural consequence of using the rules themselves: there are also many awful maps out there that follow them to the letter. The attainment of aesthetic or usability criteria must therefore depend on the quality of implementation within the use of a particular set of rules, which weakens any claim for some sort of priority.

Early days yet. This is a schematic of the London Underground designed by a computer program implemented by researchers at the Universität Karlsruhe [12, 21]. The complexity of the London network, coupled with the need to position all of the station names, is currently too much for the available computer capacity. Smaller networks can be configured much more successfully.



So, we must ask, why only lines that are horizontal, vertical, or at 45°? In fact, this doesn't just potentially simplify interpreting the design for the user, but also the design process itself. Indeed, automated map generation has become an interesting task for computer scientists, precisely because Beck's rules constrain it to the point of it being an (almost) tractable problem. Heuristics for scoring good and bad layouts are devised, and the computer is programmed to attempt a solution which attains the greatest possible overall score by maximising the presence of high scoring configurations and minimising low scoring ones. Hence, for the designer – whether human or (perhaps in ten years time) computer – the decisions that must be made are greatly simplified by using Beck's rules: need to choose an angle? Well, there's only one to choose from. Need to join two points? Just a few ways to do it. The possibilities entailed by a restrictive set of rules mean that even complex locations might have only a limited number of solutions. For example, there are really only two feasible ways to show Oxford Circus on the London Underground: with the Central Line horizontal, either Victoria Line vertical, Bakerloo Line southeast to northwest; or Victoria Line southwest to northeast, Bakerloo Line vertical.

The problem for the human designer is that, having evaded the need to think so far – both in choosing and implementing the rules – that this might be habit forming, and more specific questions concerning the design of the map are neglected. How should the routes be prioritised; should some be chosen to be relatively kink free? Could some kinks have been eliminated if something different had been tried? Are any parts of the map ambiguous or unclear? At an extreme, perhaps simple tasks such as optimising station name placements or aligning termini might be forgotten.

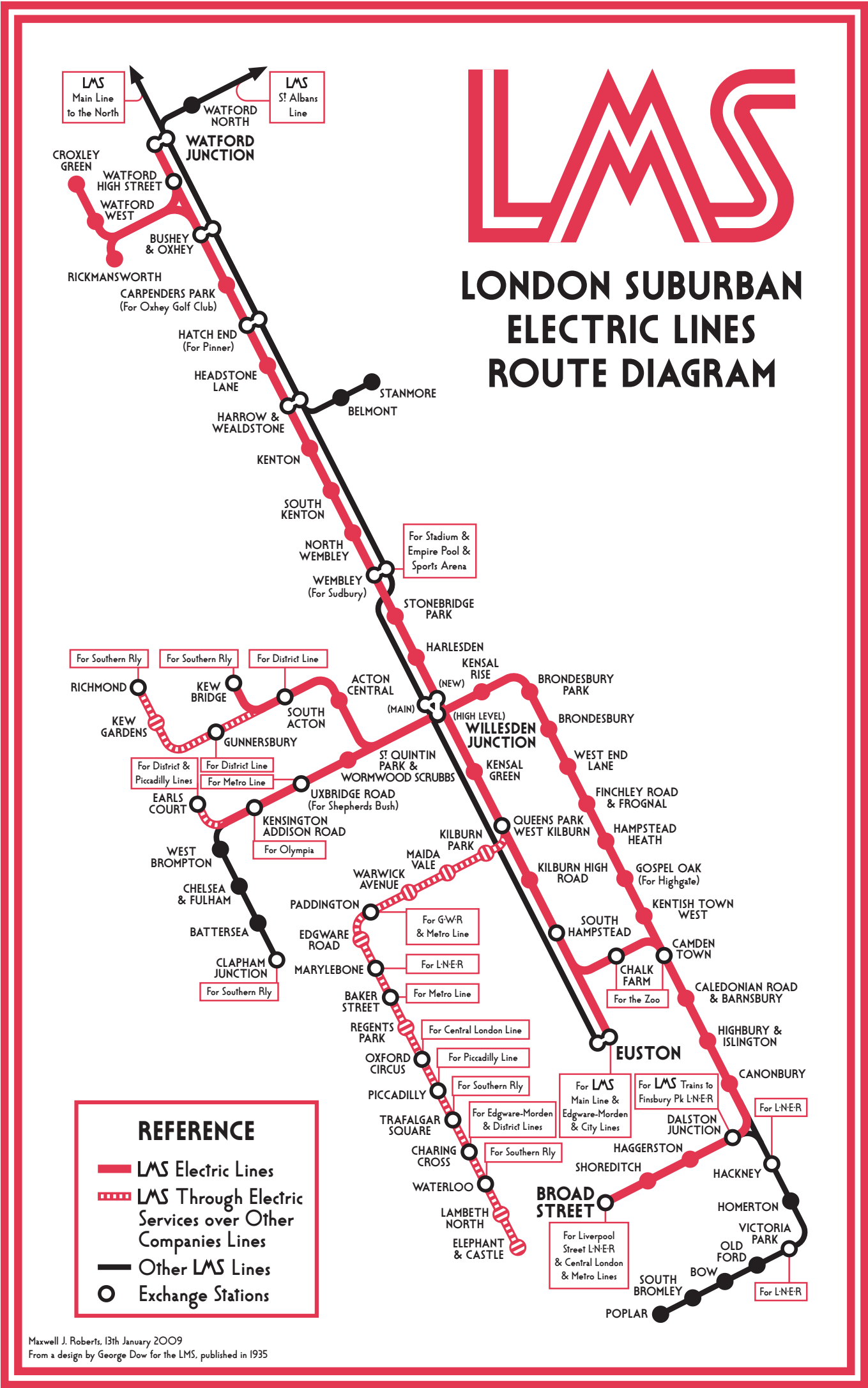
Problems with poor map design are undoubtedly compounded by modern computer graphics packages, which make the task of creating a Beck-rules map extremely easy. The entry barriers have been removed, so that what would once have been

Is the ease of use of today's computers related to any possible reduction in care and attention to detail from designers compared with times past? This is a potentially explosive question, but readers may find this map of the London Underground, designed for RATP, of interest. It is hard to find a part of the map where the designer has not made any errors. Numerous badly designed unofficial London Underground maps can be found on the internet.



a task that only a skilled draftsman could attempt is now potentially open to anyone, irrespective of whether the structure and working of transport networks, or the needs and priorities of users, are understood. A transport manager likewise without any particular sensitivity to these issues will happily accept the lowest possible tender when subcontracting the design of a map to an outside agency.

Earlier, I have argued that Beck's rules can simplify a map by removing extraneous detail and revealing underlying structure. However, I have also suggested that there might be circumstances in which Beck's rules break down. Not only this, but any designer who chooses this set of rules, without thinking carefully as to why, has placed a first step on a slippery slope towards a bad design, even for a network which is well-suited to Beck's rules. The initial phase of the process, therefore, should be to think about the properties of the network to be mapped; its shape, its nodes, its traffic flows, its likely design trouble-spots. If these can be identified, and the strengths and weaknesses of Beck's rules are known, then the designer will be in a position to determine whether these circumstances mean that the rules should be broken. At the very least, having created a map using Beck's rules, a designer should evaluate the success of the design, and whether this might be improved by using a different rule set. On the other hand, if Beck's rules are to be set aside, then this is not a decision to be taken lightly. If the intention is a map that is fit for public consumption (as opposed to bemused stares in an art gallery), it is essential that the thinking is well-motivated, and that the designer has a full understanding of what is to be broken, and why.



Not a horizontal, vertical, or 45° diagonal in sight. George Dow worked for the LNER and his schematic railway network maps were first displayed in 1929, four years before Beck's first design was published. George Dow created a map for the LMS London area electrified network in 1935. The original has been lost and no copies are known to have survived. All that remains is a poor quality monochrome reproduction from a contemporary railway magazine. This was the basis for the realisation here, attempted by the author. The original was hand-lettered, which is difficult to simulate convincingly digitally, and a new font was devised intended to mimic the original style. George Dow created a splendid exuberant design, showing just what is possible if the rules are put to one side.

Breaking the rules (I):Why 45°?

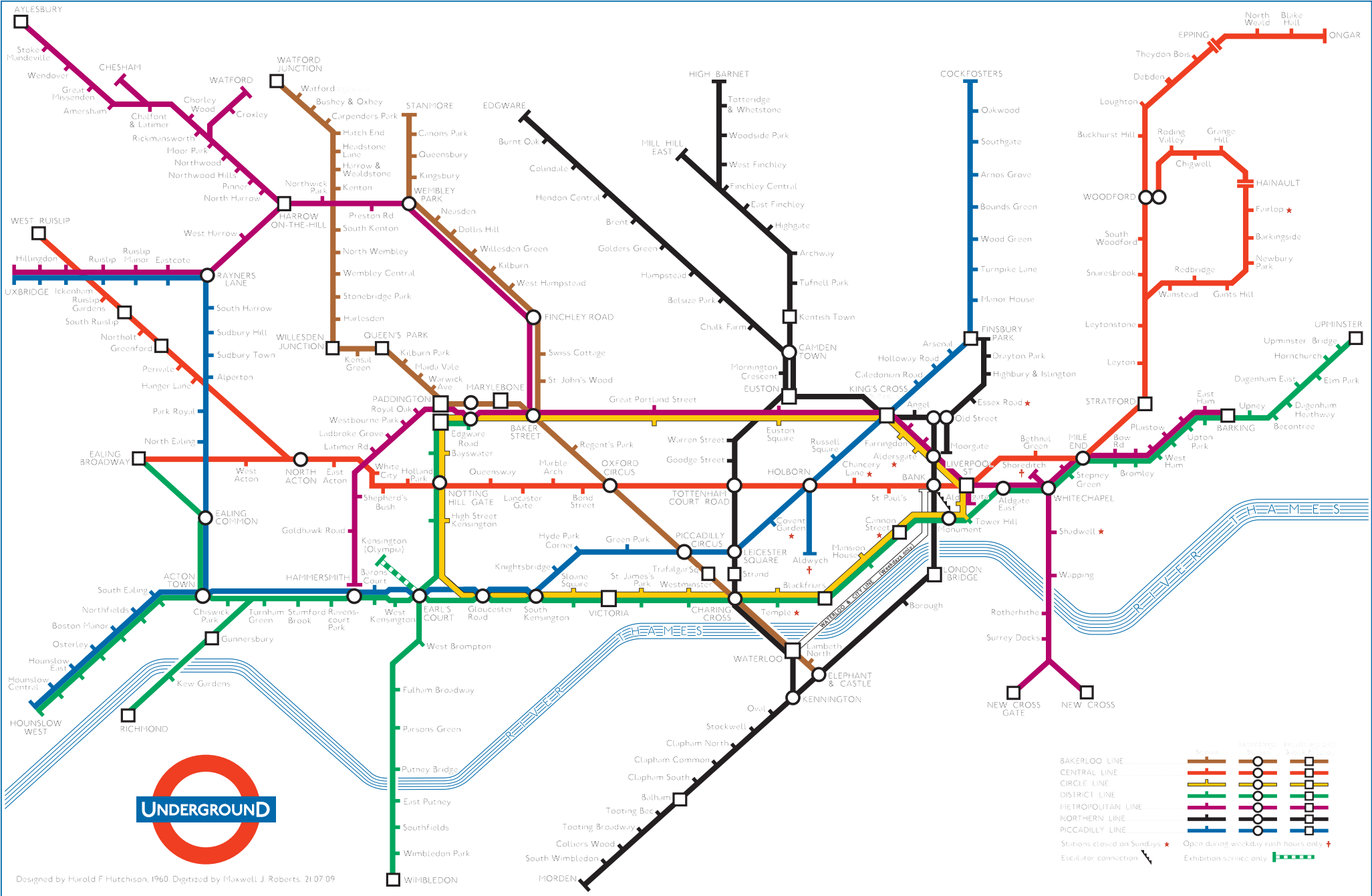
Why not something else?

Even if we continue with an *octolinear* design [21], does the diagonal angle have to be 45°? In other words, do we have to have regular increments in angles between lines (i.e. must we have *regular octolinearity*)? Certainly not. From a psychological point of view, nothing is known to suggest that lines at this angle are easier to follow than lines at, say, 60°, and so the designer would be well-advised to think about the qualities of the network early-on, making sure that 45° really is the optimum. Fortunately, this is a decision process that many do seem to undergo, as non-45° angle maps are relatively common. Whatever the decision taken, there is likely to be benefits *and costs*.

At first sight, London itself does not seem to be well-suited to a 45° angle. The built-up area is more extensive east-to-west than north-to-south, there are numerous long station names, and there is a British tradition for these to be presented horizontally rather than vertically or diagonally. In the light of this, a 45° angle will do nothing to ease the pressure on the horizontal dimension, and much of the difficulty in designing the London Underground map comes from trying to squeeze everything in to fit this without the result looking compressed. The diagonal angle affects the horizontal spread of a network, and so if there is limited space to show it, then a steeper angle may allow fewer kinks, less horizontal compression, or less geographical distortion.

In fact, Beck himself devised a 60° Underground map in 1940. Faced with the problem of extensive extensions to the east and west of the network, this solution could possibly have enabled them to be shown more comfortably. Even so, Beck was unable to show the entire eastern end of the District Line. This map only lasted one issue, and ill-conceived design features forced on Beck (each station named for every line that served it, up to three times at certain stations, and over-large interchange circles, one-per-line) make the 60° innovation difficult

How not to break the rules (I). Harold Hutchison's notoriously inept successor to Beck's work has jagged corners and lines crushed together at interchanges. More relevant, but for reasons lost in history, this map adopted 42° as the diagonal angle, putting the design into great difficulty. For example, this splays out the Piccadilly and Bakerloo Lines, considerably enlarging the gap between Baker Street and Kings Cross, and crushing the area around Paddington and at Moorgate as a result.



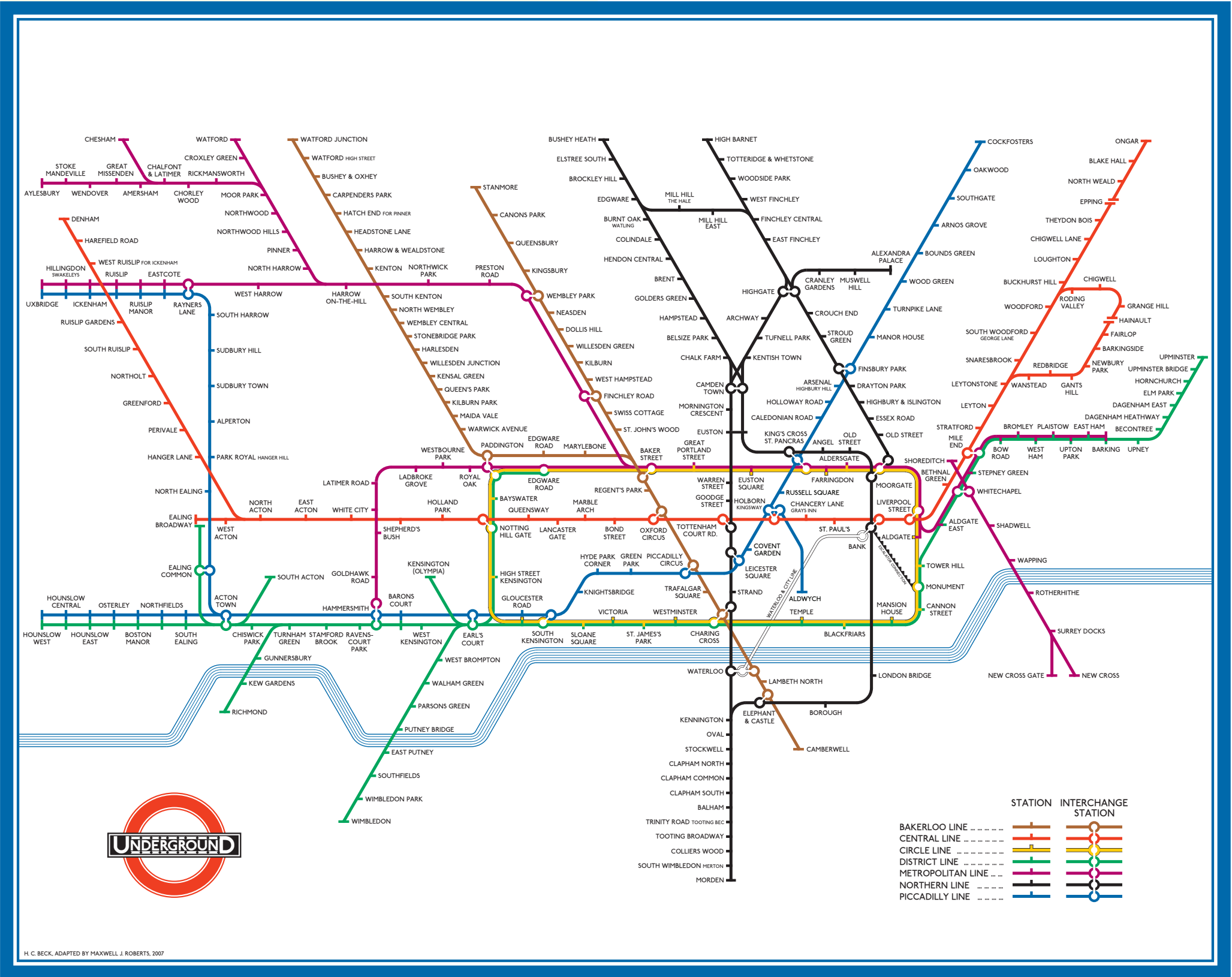
to evaluate. To get around this problem, I have produced a version of the map without these features, and reflecting the line colours, interchange styles, and station names of the early 1950s.

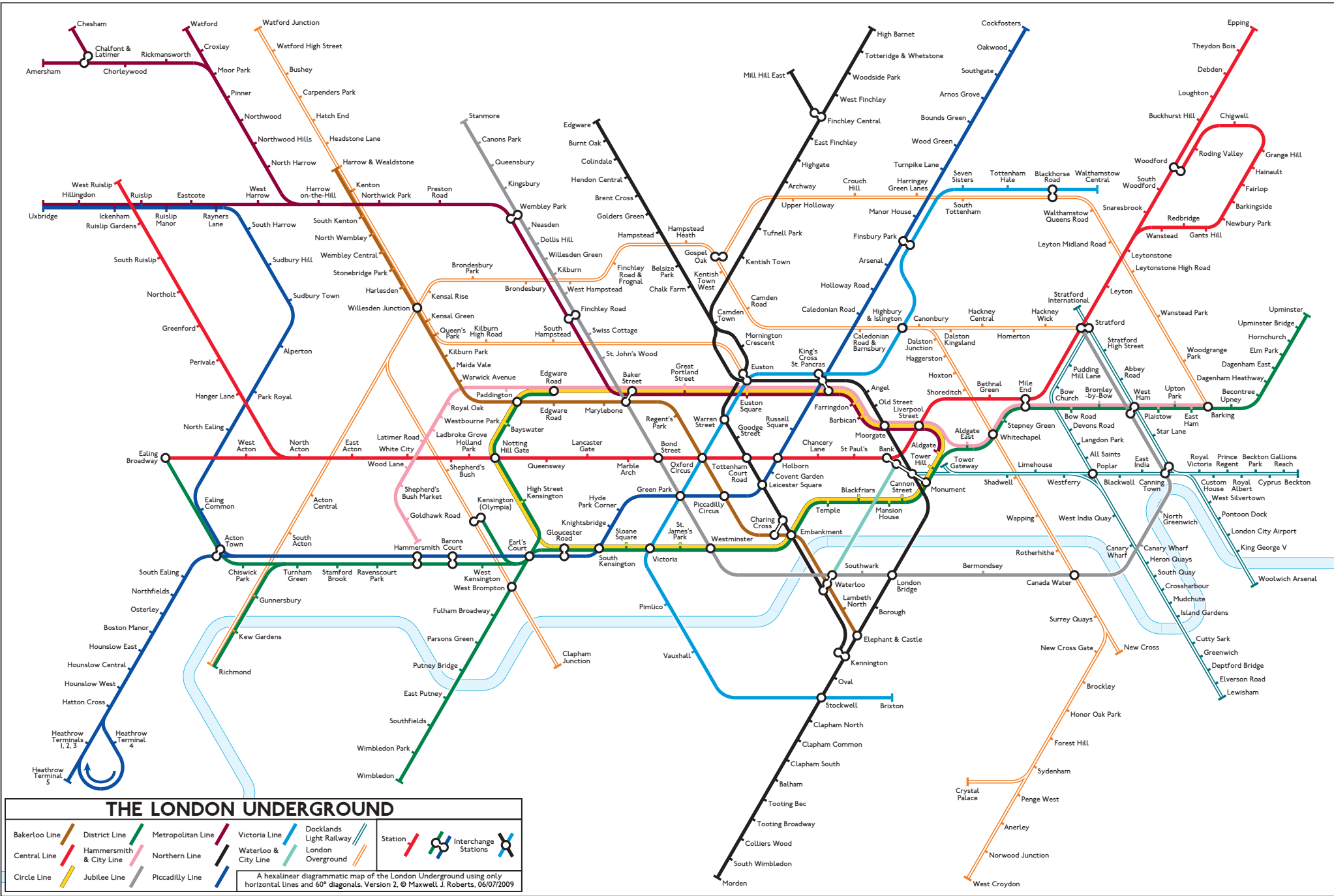
With this map, we can see that the 60° angle was only a partial solution to the problem of horizontal spacing. The east side of London is rather cramped compared with West London (which takes up a disproportionate amount of space on the map), although it is indeed possible to show the entire District Line. The fundamental difficulty, however,

Beck's 60° map of 1940 had many poor design features which were forced on him by management. We can better evaluate the success of departing from the 45° rule by stripping the map of these. The result (created by the author) reflects the station names and styling of the early 1950s, along with showing the uncompleted extensions. Fundamentally, the principles underlying this design are sound, and it is neither confused nor unattractive. However, Beck was set to tread a more radical path using conventional rules. Technically, this is an *irregular octolinear* map: the angles of the lines are at uneven intervals.

Strictly this is a *regular hexalinear* map. It nonetheless demonstrates that breaking the rules can potentially have benefits. The 60° angle seems to suit Central London better than 45°, leading to far fewer kinks inside the Circle Line than would normally be possible. For any network, some exploration and thought by the designer as to optimum angles could result in an improved design.

is that even if 60° permits horizontal compression of the lines, it will still have no effect on the horizontal width of the station names. For a network expanding eastwards rapidly, more drastic action is necessary if horizontal compression is to be achieved. Overall, for London, the 60° angle did not serve Beck's purposes sufficiently for him to persist with it, and his eventual solution was to use vertical lines rather than 60° (giving the least horizontal spread of all); to retain 45° diagonals where necessary to prevent excessive kinking in Central London; but to minimise their use elsewhere. Effectively, Beck began to focus on making his designs dominantly *tetralinear* with as few exceptions as possible. However, the ultimate





expression of this philosophy (from 1954 to 1960) led to maps with several difficult-to-identify routings where lines branched, many 90° bends, and extreme geographical distortion (see Box 3).

In order to investigate these issues further, we need to think about breaking another rule, unique to the London Underground map: that it must conform to its historic dimensions dating from 1933. It makes little sense with an expanded network and today’s difficult-to-read cramped design, and increasing the area enables us better to identify the potential benefits of breaking the more important rules. One outcome, shown here, is a 60°-based map of the current London Underground network and associated services. Strictly, this map is hexalinear (it has no vertical lines). Surprisingly, despite being more constrained, it actually has *fewer* kinks inside the Circle Line (six) compared with the minimum possible for an octolinear map of the same size (nine). East London works particularly well, West London less so, but the overall result certainly suggests that, ironically, as far as Central London is concerned, it is better suited to a 60° diagonal than the 45° one that it has been associated with for over 70 years. The possibility that different parts of the same network might be more suited to

different angles should make all designers pause for thought. If nothing else they should be aware that, for at least some instances, breaking the 45° rule can result in maps that are better matched to the properties of the network being depicted, resulting in improvements in usability.

Breaking the rules (2): Why octolinearity? Why not higher linearity?

In theory, restricting the diagonals on a map to one angle (i.e. hexalinearity or octolinearity) creates a simple and coherent design. When identifying routes, users only need to follow lines that go in six or eight directions. However, with a well-chosen contrasting set of line colours, the human eye does not need this sort of angular assistance in order to follow a trajectory easily. On the other hand, irrespective of the actual angle of diagonal chosen, restricting this simplifies the decision processes of the designer enormously, which might be a good thing. After all, designers are human too, and giving them too much to think about might also lead to cognitive overload and poor solutions.

Why then complicate matters by even thinking about progressing to higher linearity? Too many



How not to break the rules (2). Multiple angles enable the designer to get around self-inflicted problems in the centre of London. For example, compare Covent Garden with Hyde Park Corner. The arbitrary breaking of the single-angle rule introduces an disorder into the design with no payback.

angles, carelessly implemented, can result in maps that look visually disturbing [15, p. 87]. Adding angles can also act as a crutch for a lazy or a bad designer, permitting a job to be finished quickly rather than forcing a rethink: if two points can't be linked by a 45° diagonal, try a different angle instead. It is not hard to spot maps that fall into this trap, they look amateurish because breaking this rule accentuates the poor design. The designer not only got into difficulty, but also broke a key rule in order to bodge a solution, and without any better reason for doing this, the orderliness of the map is disrupted with no payback.

The answer is that in some circumstances, carefully using higher linearity (which need not be regular, and could encompass any angles at all; infinite linearity) can indeed result in a clear payback. Perhaps a map is possible in which irrelevant meandering curves are straightened, but in which

there is less geographical distortion. Perhaps a more compact map can be made, or else one in which the numbers of kinks are reduced. For example, instead of a horizontal line kinking to 45° on an octolinear map, a straight line might be possible on a dodecalinear map. Higher linearity is nothing new [4, p. 30] and was used to striking effect in Moscow during the 1970s.

Henry Beck himself experimented with this towards the end of his life. Even after London Transport dispensed with his services, he still took an active interest in the design of the Underground map and, faced with the addition of the Jubilee Line, this was one solution that he tried [5, p. 76]. However, without a computer, such experiments would have been impossibly handicapped, and they seem never to have progressed beyond uncompleted sketches in notebooks.

If we adopt higher linearity simply to reduce the number of kinks on the map (as opposed, say, to increasing compactness), we are faced with a trade-off. More angles equals fewer kinks, but potentially less coherence. Entering into this realm is a considerable test for the designer, identifying

the best compromise and considering the possibility that each level of linearity has its own aesthetics: solutions that work well and look attractive, versus solutions that work badly. The higher the linearity, the more the designer is tested: a careful decision is necessary about the trajectory of every single line, and adjusting one can result in the need to adjust many others. Even in situations where the angle of a line is not particularly constrained by the nodes that it connects, its trajectory should not be arbitrary. Symmetrical and parallel lines should be used whenever possible so that there is some organisation to the map that the user can relate to.

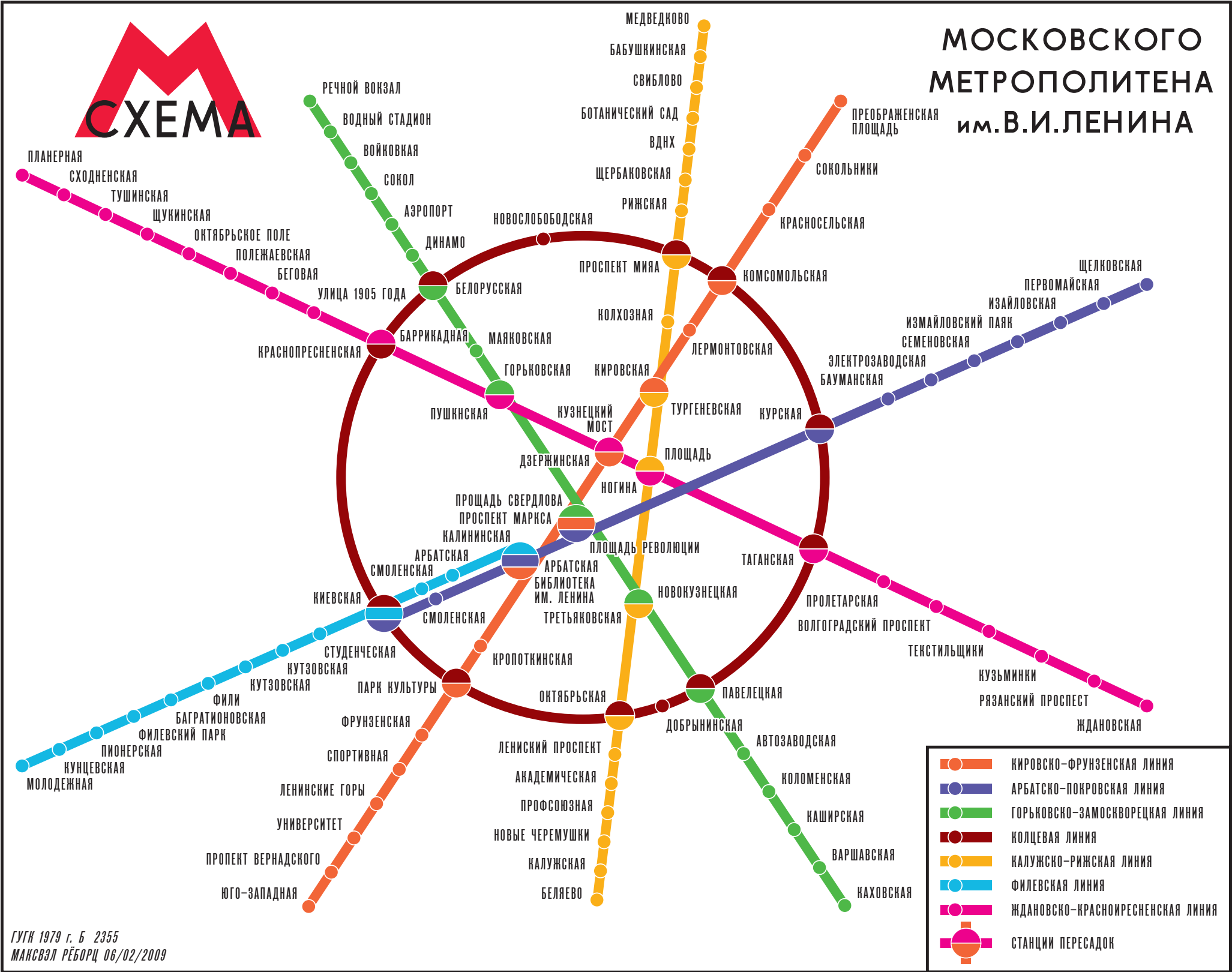
The *dodecalinear* example shown here reduces the number of kinks in Central London to just three. Overall, the total angles subtended by all the arcs on the map is considerably less than what is possible with an octolinear map. Is this map likely to be easier to use or more attractive and engaging?

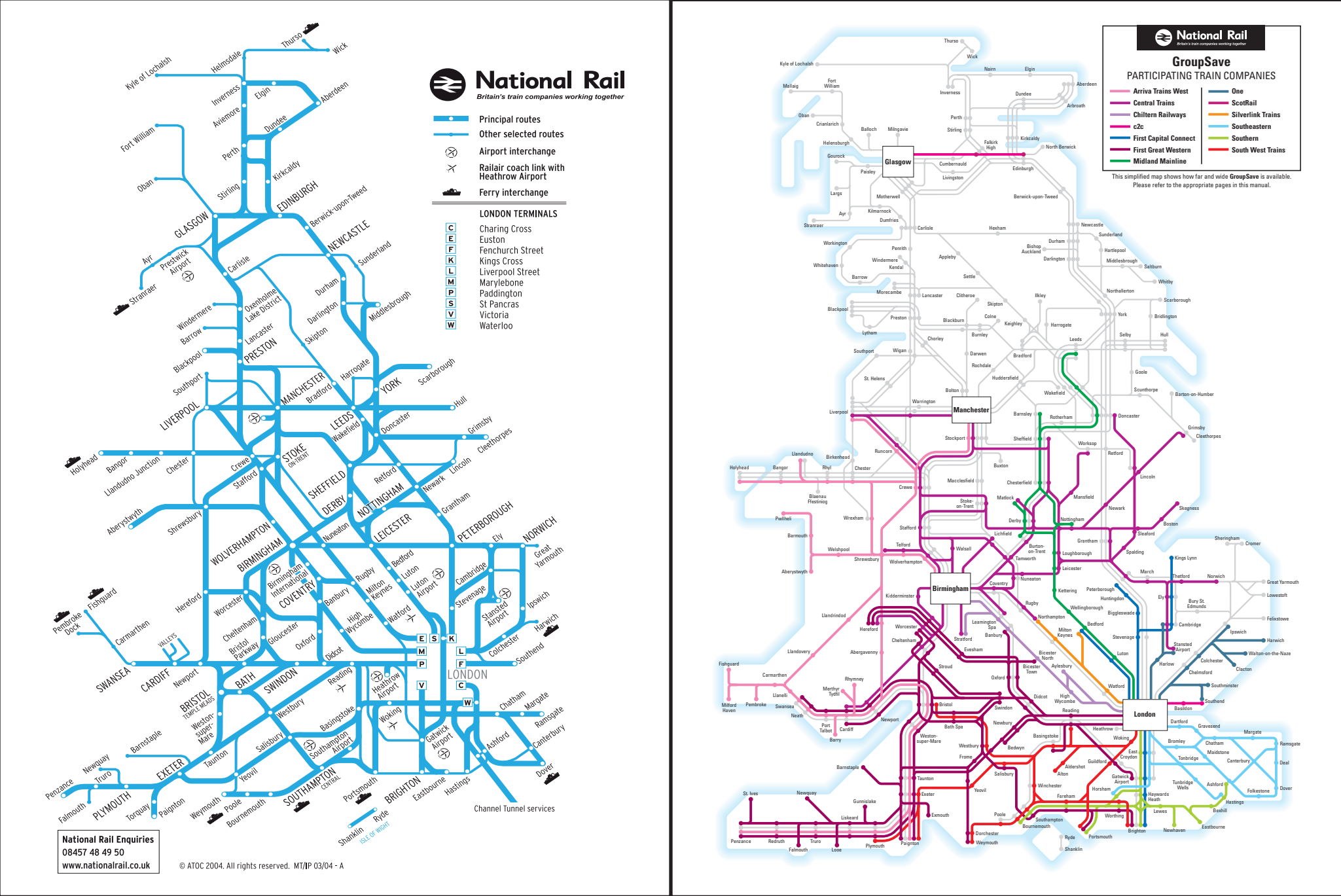
Only objective usability studies can definitively answer such questions. However, initial reactions

to higher linearity London Underground maps are very varied. An official map, following Beck's rules, has become so much part of people's expectations that maps that depart radically from the norm can generate adverse reactions for reasons extraneous to their usability and attractiveness. Of course, this will not be a problem for networks that are unfamiliar, or whose schematics are less of a part of the cultures of their users.

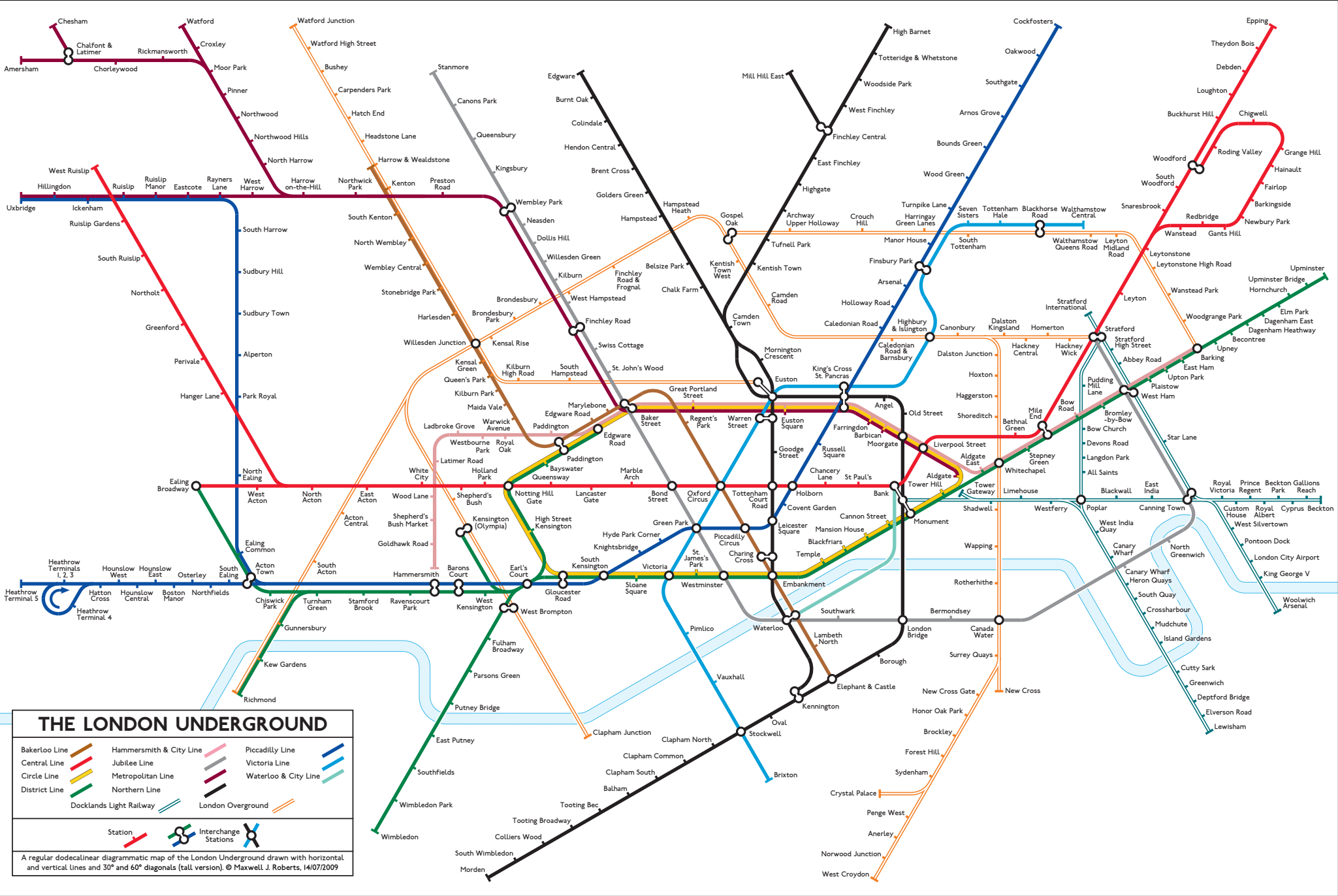
It is possible that the biological properties of the human nervous system mean that the

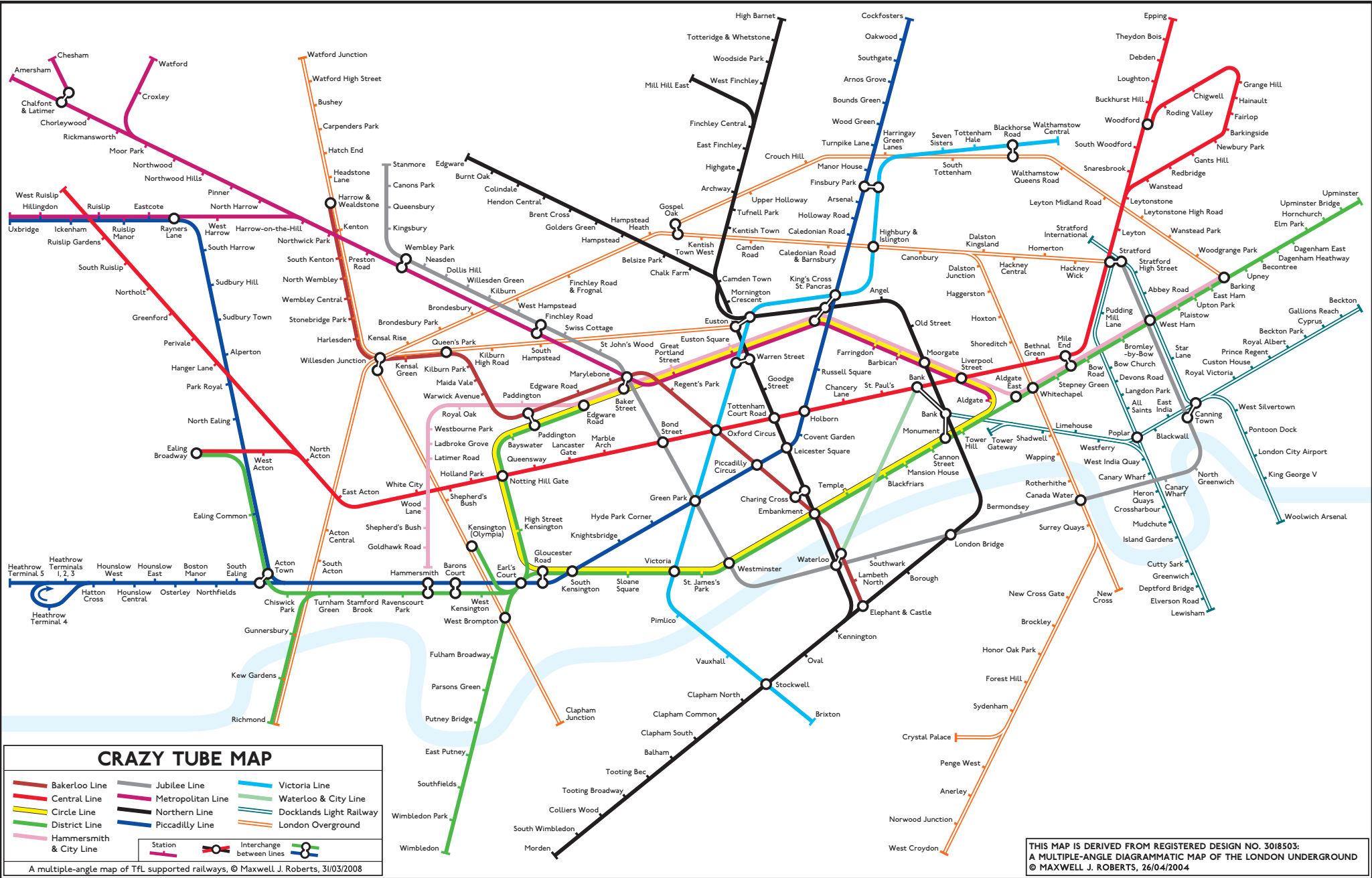
In the 1970s, the Moscow Metro had an almost perfectly radial network and, famously, the maps of the time used higher linearity and had no kinks at all. Unfortunately, interchanges between lines were clumsily shown (not helped by their having multiple names), and by the time a better convention had been developed, the network had expanded to the extent that the zero-kink approach was no longer feasible. The map here, devised by the author, combines the 1970s network and design with 1980s interchanges, emphasising the bold, striking approach taken by the original designers. The perfect transport schematic?





Dodecalinear (left) and Octolinear (right) maps of Britain's railways. Here, it is the octolinear map that is poorly suited to Britain's geography. There is nothing intrinsically disturbing about the dodecalinear map.





An angle too far? Infinite linearity is enormously unforgiving and difficult to implement. The more kinks that are removed, the more the ones that remain look like design flaws. However, the outcome here is just one kink inside the Circle Line. In practice, the law of diminishing returns means that the loss of coherence compared with the dodecalinear map probably does not make up for the reduction in kinks, but even this map has its advocates. For the appropriate network (one that is highly radial), this might well be the right approach.

representational or perceptual features of higher linearity maps make them intrinsically off-putting and perhaps difficult to use, hence the evolution and adoption of Beck's rules to prevent the creation of such maps. However, there is currently no evidence to support this, and the substantial individual differences in preferences that people demonstrate goes against a biological explanation.

This *regular dodecalinear* map has horizontal, vertical, 30° and 60° lines. This reduces the number of kinks inside the Circle Line to just three, with reduced kinks elsewhere on the map. It is possible to reduce the number of kinks even further with higher linearity still (the minimum possible is just one inside the Circle Line) but such multiple angle maps are not for the fainthearted designer or user.

An alternative reason for people's discomfort, therefore, is that many are so used to the 'language' of octolinear maps, that they find one that speaks an unusual 'dialect' to be objectionable. This gives us cause for optimism, because it implies that people should be able to adapt to maps that are potentially easier to use.

In summary, a higher linearity map would be an interesting solution to try when faced with a complex network of radial lines, for which octolinearity would necessitate many kinks in order to show them. The potential payback would be that many or even most of the kinks could be eliminated. It is not a project for the fainthearted, and tests the skills of the designer to the limit. Even then, the user, familiar with more conventional mapping techniques, might resist the outcome if the benefits of the new design are not immediately obvious.

Breaking the rules (3): Why straight lines, why not curves?

Experimenting with higher linearity might seem radical enough, but having gone this far, we should consider asking why a map should consist of straight lines only. Henry Beck famously referred

to the “vermicelli” of the Underground map prior to his own [3], but surely it is the many *superfluous* twists and turns that made this design objectionable, rather than the mere presence of curves in their own right. After all, these are intrinsic to the natural world, and for the Ancient Greeks a circle was considered to be the perfect shape. Curves by themselves are not inherently wrong and therefore, in theory, should not be problematic.

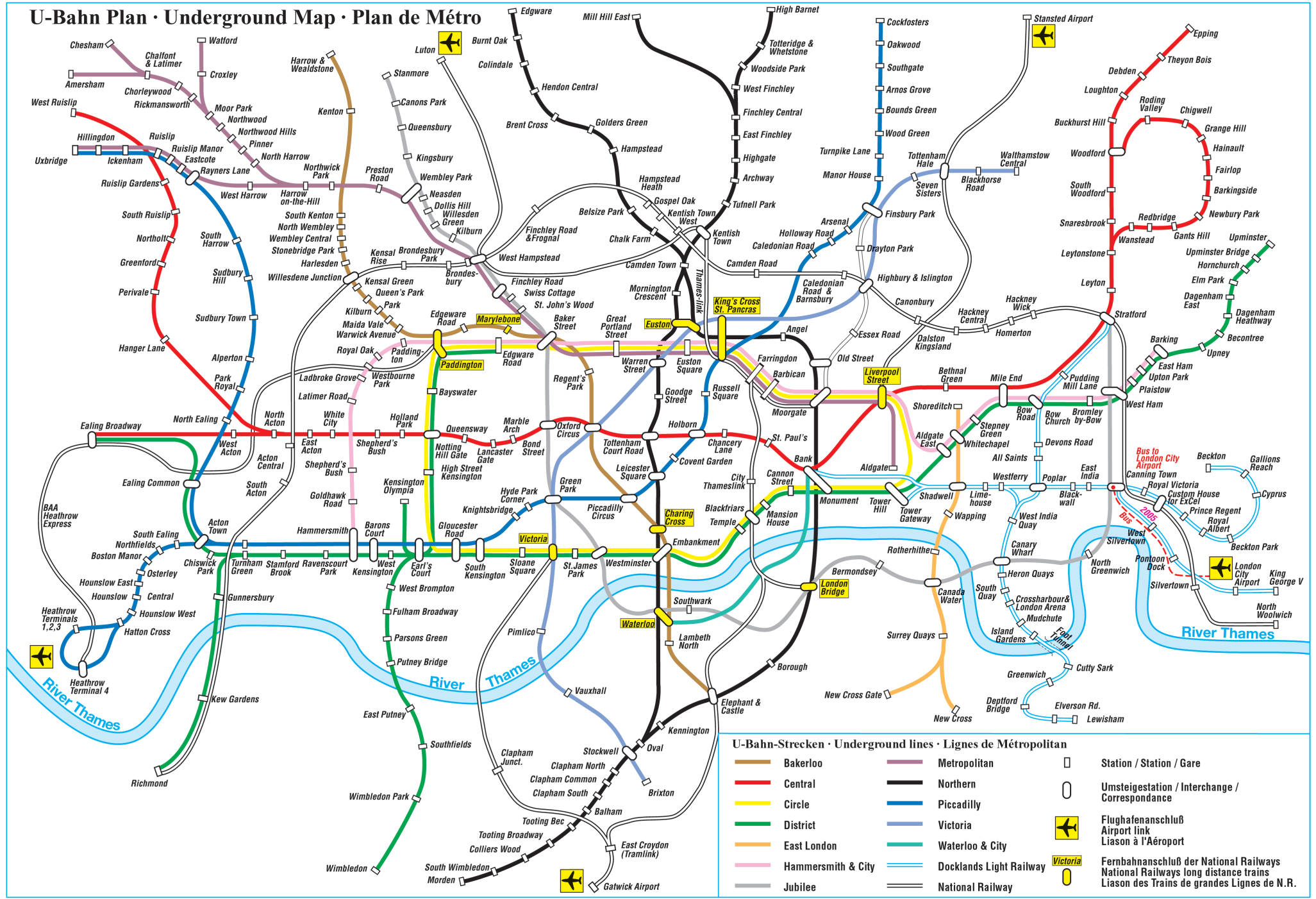
The basis of an octolinear, or indeed any linear map, is that a straight line is the easiest trajectory to follow, and therefore only straight lines should be used. However, this thinking is challenged as soon as kinks are added. With several of these within a short distance the notional advantages of attempting to dominate a map with straight lines are undermined. Hence, on the official Underground map, Warren Street to Camden

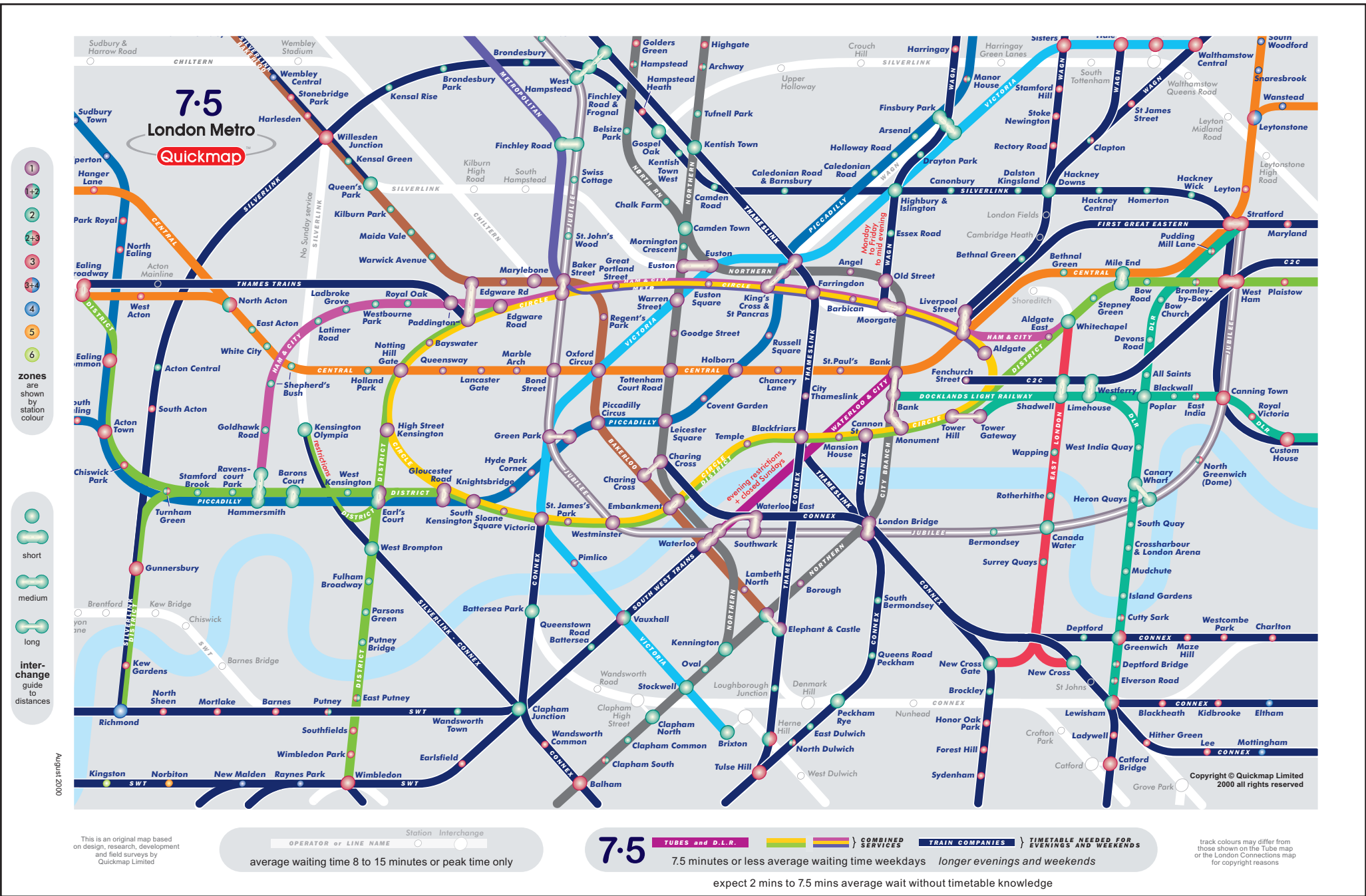
Quickmap have experimented with sweeping curves. Several have been used on their 2000 map of Inner London’s railways. However, there is some inconsistency in the extent to which different lines were given this treatment, and there are many straight line segments still on the map, reducing the overall impact of trying this technique.

Town on the Northern Line and Bank on the Central Line are particularly problematic. Replacing sequences of kinks with gentle curves is therefore an option that should be seriously considered. A harsh-looking map, with many complex kinks, can potentially be softened by using trajectories that are less difficult to follow, making it easier to use, as well as more inviting to look at.

What sorts of networks might lend themselves to an all-curves approach? Primarily, ones in which the lines cannot make up their minds. If a line changes direction and back again, interchanging with others in the process, several awkward kinks may be necessary even with a higher linearity approach, resulting in no significant payback in attempting to create a network based upon straight lines. At an extreme, with many lines continually crossing each other and back again, and with stations whose

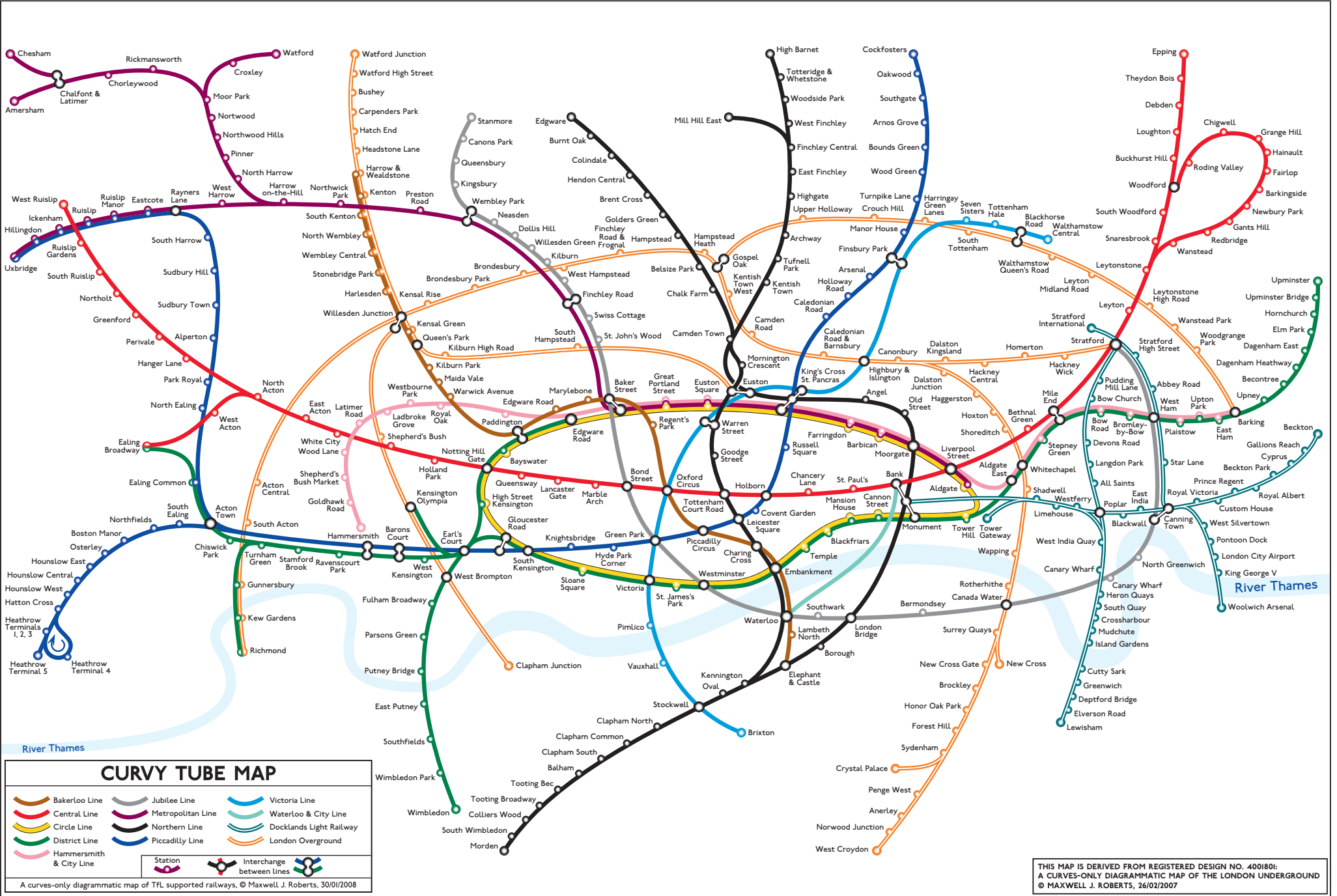
How not to break the rules (3).The curves give this map a distinctive fun appearance, but they don’t obviously reduce the visual complexity in any way.All too often, they increase it.A possible case of a good idea let down by its implementation,this map directly inspired the author to attempt all-curves designs.





relative spatial locations must be preserved on the map (the Paris Metro has numerous examples, see Box 2), then the kinks can result in very many

[Below] Gentle curves potentially give a London Underground map an inviting friendly appearance, and simplify it by removing the harsh transitions in direction.



zig-zags that overwhelm the design, potentially alienating people and deterring them from attempting to use it. Here, it is possible that an all-curves approach can have a considerable payback.

For the designer, attempting an all-curves map of the London Underground is a far more forgiving exercise than a higher linearity approach. Changes in direction no longer look like clumsy design flaws so that, for example, gentle undulations on the eastern side of the District Line do not draw attention to themselves. Also, such a map is much more amenable to alteration and adjustment, so that a change in the trajectory of one line need not result in requiring entire sections of map to be redrawn. Even so, there are aesthetic considerations for this type of design. It is better to avoid S-bends, and too many wave-like undulations can be disturbing. The objective with an all-curves approach should be to replace as many sequences of kinks as possible with transitions so gentle, that at no point along the lines are changes in curvature obvious. Converting numerous kinks into many undulating waves will just induce sea-sickness.

An all-curves attempt for the London Underground network is shown here. In terms of reactions to this, it tends to polarise people. Roughly half find it playful and engaging, but half dislike its anarchy. Preliminary usability studies suggest that this particular map is certainly no worse than conventional alternatives, especially for people without prior prejudices about ‘good’ design [10]. This leads us back to considering the importance of *map engagement* as opposed to *map usability* in encouraging map usage and network travel, and leads to the possibility that perhaps transport undertakings should offer users different maps to reflect their preferences. Overall though, I am not advocating such a dramatic change in style for all networks, but an all-curves approach is certainly one that should be taken seriously when a designer is faced with a particularly difficult system, especially one where the lines are so twisted and entwined that they cannot easily be untangled (see Box 2).

Conclusions

Henry Beck’s rules, also known as *regular octolinearity*, have served us well for many years but, especially for complicated transport networks, and more and more as networks become larger and larger, it is possible to identify circumstances where these rules are likely to, and indeed do break down for psychological reasons. An awareness of what a schematic map is trying to achieve, how and why this helps the user, and the design qualities of good versus bad schematics, is essential in creating and evaluating designs.

We must never assume that a standard set of rules will fit every network. History has proven this type of assumption wrong time and time again in many different settings. A slavish adherence to Beck’s rules runs the risk that an unusable and unattractive design will result. When a map is proving difficult to implement, the solution is therefore not to ignore such problems and carry on regardless, it is to consider why Beck’s rules do often work, and what alternatives should be considered when they do not.

Rules can be broken, or new ones created, but we have to know why we are doing this. Without this self-reflection, a poor design is likely. With insufficient thought, the alternative rules may be just as unsuitable for the task at hand. Furthermore, insufficient thought during the initial stages of the design process is symptomatic of the possibility that there will be little care and attention for the successive stages too. Even so, the thoughtful selection of a particular set of rules can never guarantee success, this is only the first step towards a sound design. Careful, considered implementation within the constraints of the rules, taking into full account the needs and likely psychological responses of the users, will always be necessary too.

Notes

- [1] BBC Television (1987). *Design Classics*. First broadcast 29th June.
- [2] BBC Television (2006). *The Culture Show*. First broadcast 16th March.
- [3] Beck, H. C. (1964). Letter to R. M. Robins, London Transport Board, 7th April. Reproduced in Leboff, D. (1985). *The London Underground map*. Unpublished dissertation, Oxford Polytechnic.
- [4] Dow, A. (2005). *Telling the passenger where to get off*. Harrow Weald: Capital Transport Publishing.
- [5] Garland, K. (1994). *Mr Beck's Underground map*. Harrow Weald: Capital Transport Publishing.
- [6] Horne, M., Roberts, J. and Rose, D. (1986). Getting there: an assessment of London Transport's endeavour to improve bus passenger information literature for Central London, 1979–1985. *Information Design Journal*, 5, 3–27 & 87–110.
- [7] Klippel, A., Freska, C., & Winter, S. (2006). You-are-here maps in emergencies: The danger of getting lost. *Journal of Spatial Science*, 51, 117–131.
- [8] Leboff, D., & Demuth, T. (1999). *No need to ask!: Early maps of London's Underground railways*. Harrow Weald: Capital Transport Publishing.
- [9] Meo, M., Roberts, M. J., & Marucci, F. S. (2007). Element salience as a predictor of item difficulty for Raven's Progressive Matrices. *Intelligence*, 35, 359–368.
- [10] Newton, E. J., & Roberts, M. J. (2009). *Applying cognitive psychology principles to London Underground map design*. Poster presented at London South Bank University, June.
- [11] Newton, E. J., Roberts, M. J., & Lagattolla, F. (2008). *Applying cognitive psychology principles to metro map design: A journey planning study*. Poster presented at London South Bank University, June.
- [12] Nöllenburg, M. (2005). *Automated drawing of metro maps*. Technical Report 2005-25, Fakultät für Informatik, Universität Karlsruhe.
- [13] Ovenden, M. (2003). *Metro maps of the world* (2nd ed). Harrow Weald: Capital Transport Publishing.
- [14] Ovenden, M. (2008). *Paris Metro style in map and station design*. Harrow Weald: Capital Transport Publishing.
- [15] Roberts, M. J. (2005). *Underground Maps After Beck*. Harrow Weald: Capital Transport Publishing.
- [16] Roberts, M. J., Newton, E. J., & Lagattolla, F. (2008). *Cognitive Capacity and Reasoning: Implications for Metro Map Design*. Sixth International Conference on Thinking, Venice, August.
- [17] Roberts, M. J., Welfare, H., Livermore, D. P., & Theadom, A.M. (2000). Context, visual salience, and inductive reasoning. *Thinking and Reasoning*, 6, 349–374.
- [18] *Rail* (2004), No 484, March 31st, p. 48.
- [19] *Railwatch* (2004), No 99, April, p. 4.
- [20] Vertesi, J. (2008). Mind the gap: The London Underground Map and users' representations of urban space. *Social Studies of Science*, 38, 7–33.
- [21] Wolff, A. (2007). Drawing subway maps: A survey. *Informatik*, 22, 23–44.

Web Pages (all accessed 29/07/09)

Unofficial maps illustrating points made in the text can be found at the following locations:

<http://www.amadeus.net/home/new/subwaymaps/en/london.htm>

<http://www.columbia.edu/~brennan/subway/>

http://www.johomaps.com/eu/ire_uk/uk/london/main.html

<http://www.geocities.jp/emikoabe50/subway/mappage/london2.gif>

The author's web page is:

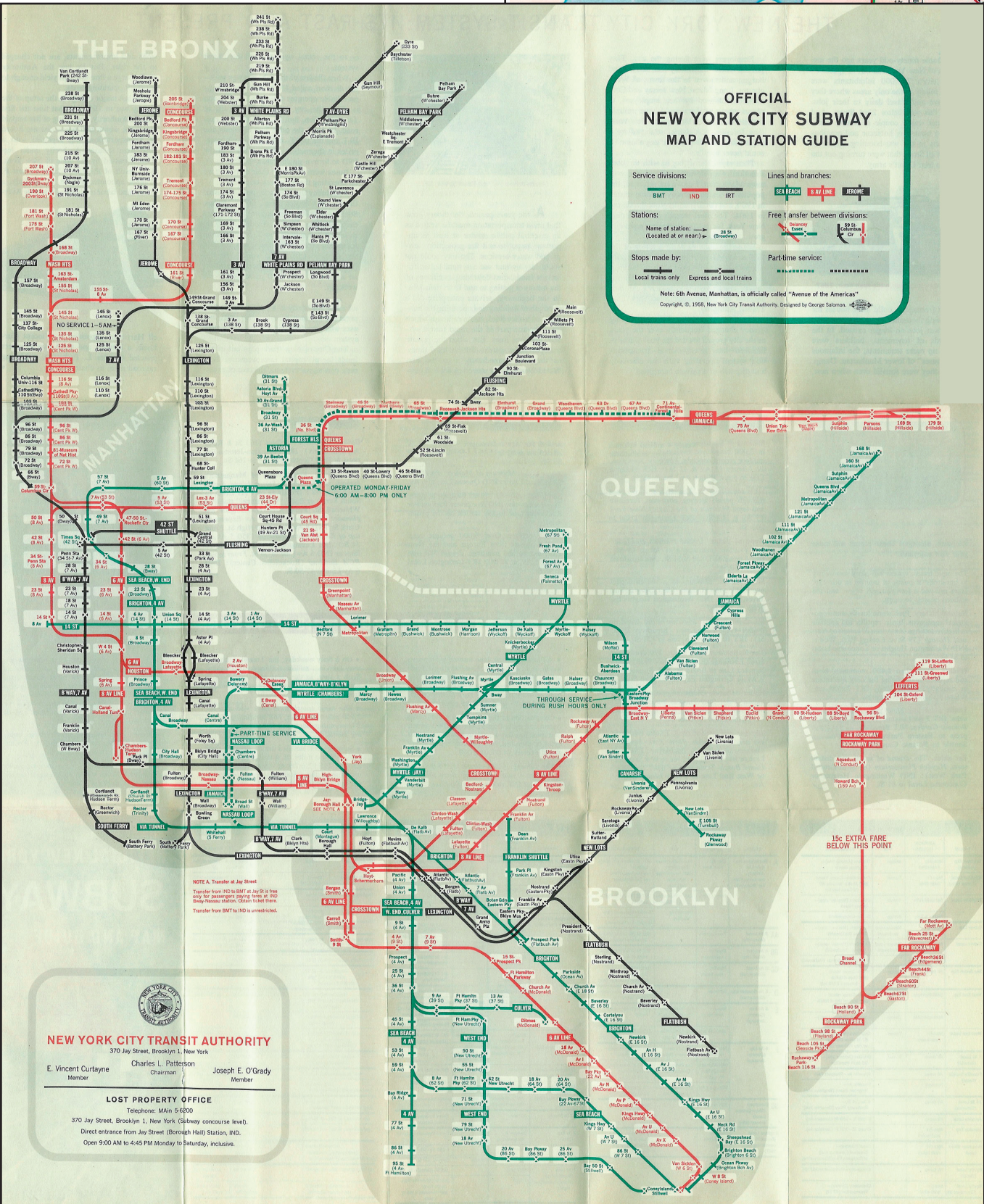
<http://www.tubemapcentral.com>

The current London Underground map can be downloaded from:

<http://www.tfl.gov.uk>

Box 1 New York: An aversion to Beck's rules?

The New York subway is an extensive network, stretching deep into the suburbs, but unlike the London Underground it is more comprehensive and its density more evenly spread, and the distances between stations are more equally-spaced throughout, resulting in less pressure on the designer to distort geography. Indeed, the station naming convention – they are named after intersecting streets – can be a positive deterrent. For example, there are five separate stations in Manhattan called 23rd Street. Add to this the complexity of the network, with express and local trains, and very different service patterns at different times of the day, and different days of the week, and the result is that a compact diagrammatic map would be hard-pressed to show all the necessary details clearly. In Manhattan, the lines themselves follow the major avenues, but do not particularly define the Central Business Districts. Instead, the shore-line of Manhattan Island plus Central Park, shown on most maps, performs precisely this task.



[Left] George Salomon's diagrammatic Subway map, issued from 1958 onwards. It did not go as far as Salomon wished, he had hoped that more extensive colour coding would be used in order to show the major service groups. The NYCTA did not wish to change the signage, and so the map persisted with the archaic practice of colour coding by historical ownership of the lines.

[Above] New construction in the 1960s resulted in a complete recasting of services, and new colour codes to identify them at stations. Adapting the Salomon map increased the quantity of information, and ruined its clarity.

[Top Far Right] The Vignelli Map of 1972 was effectively an attempt to tame its predecessor, but despite a smoother, more modern design, it perpetuated the same failings.

[Right] New Yorkers now have a comprehensive semi-geographical map that is distinctly non-diagrammatic, but successfully uses colour to show the major service groups. The level of supplementary information might be off-putting to a non-expert user. Many amateur attempts at fully diagrammatic maps can be found on the internet.

New York is more or less a grid city, with the major Subways following the lines of the streets, but the current Subway map is not diagrammatic. The widespread belief is that New Yorkers had such a map designed for them for the first time in the 1970s, and they did not take kindly to it, disliking the abstract presentation and geographical distortion entailed by a diagrammatic map. In fact, this is incorrect, and one had previously been created by George Salomon and issued from 1958 onwards. It appears to have been successful but, unfortunately, a major construction project, the Chrystie Street connection (completed in 1967) resulted in a complete recast of services. To help New Yorkers adjust to this, Salomon's design was altered, inexpertly, to show individual routes.

This paved the way to a major redesign by Massimo Vignelli in 1972. Unfortunately, the colour-coding of the individual routes, as used on station signage, was perpetuated on this version. Banding together contrasting colours deconstructed the map, concealing rather than emphasising the underlying service groups that followed the

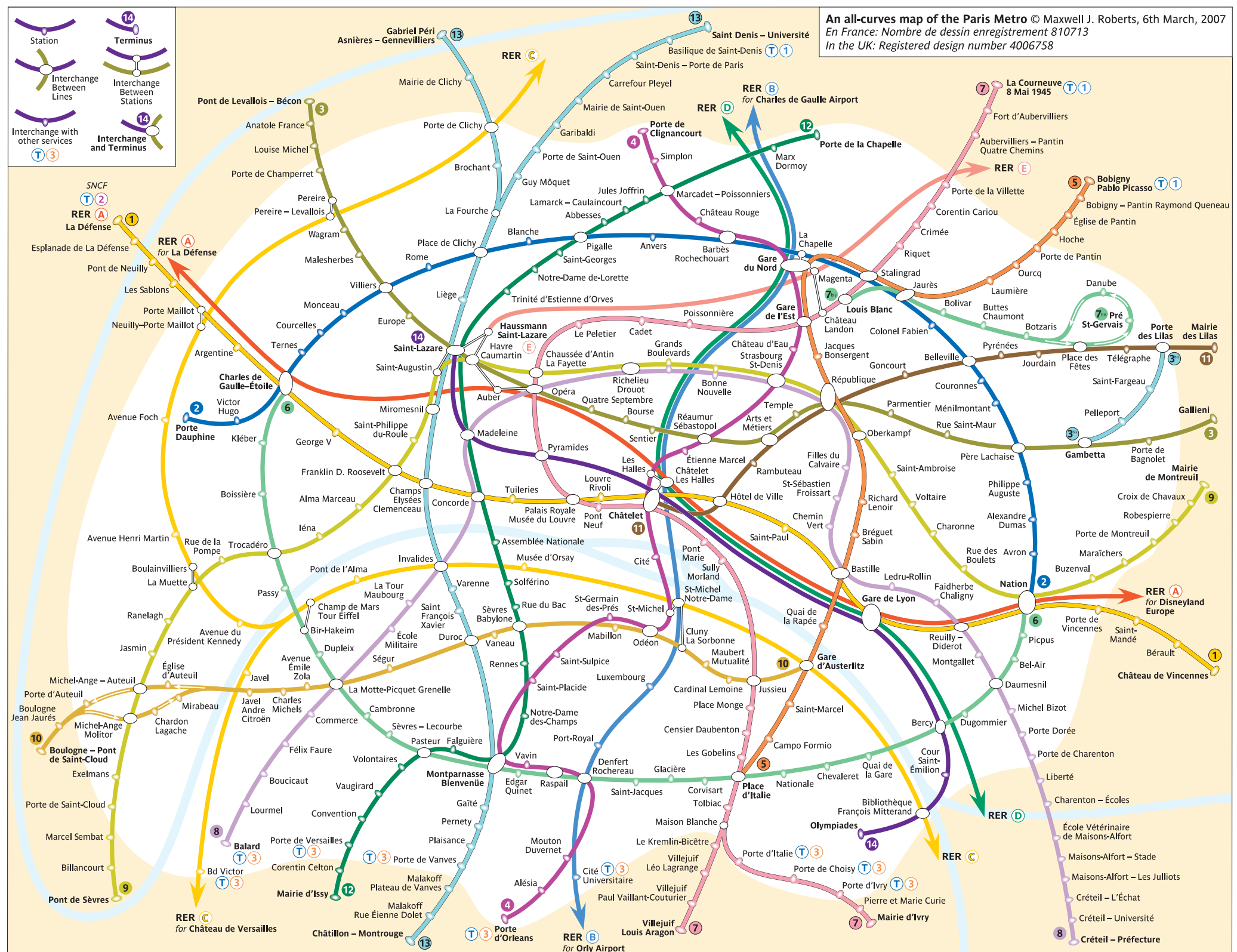
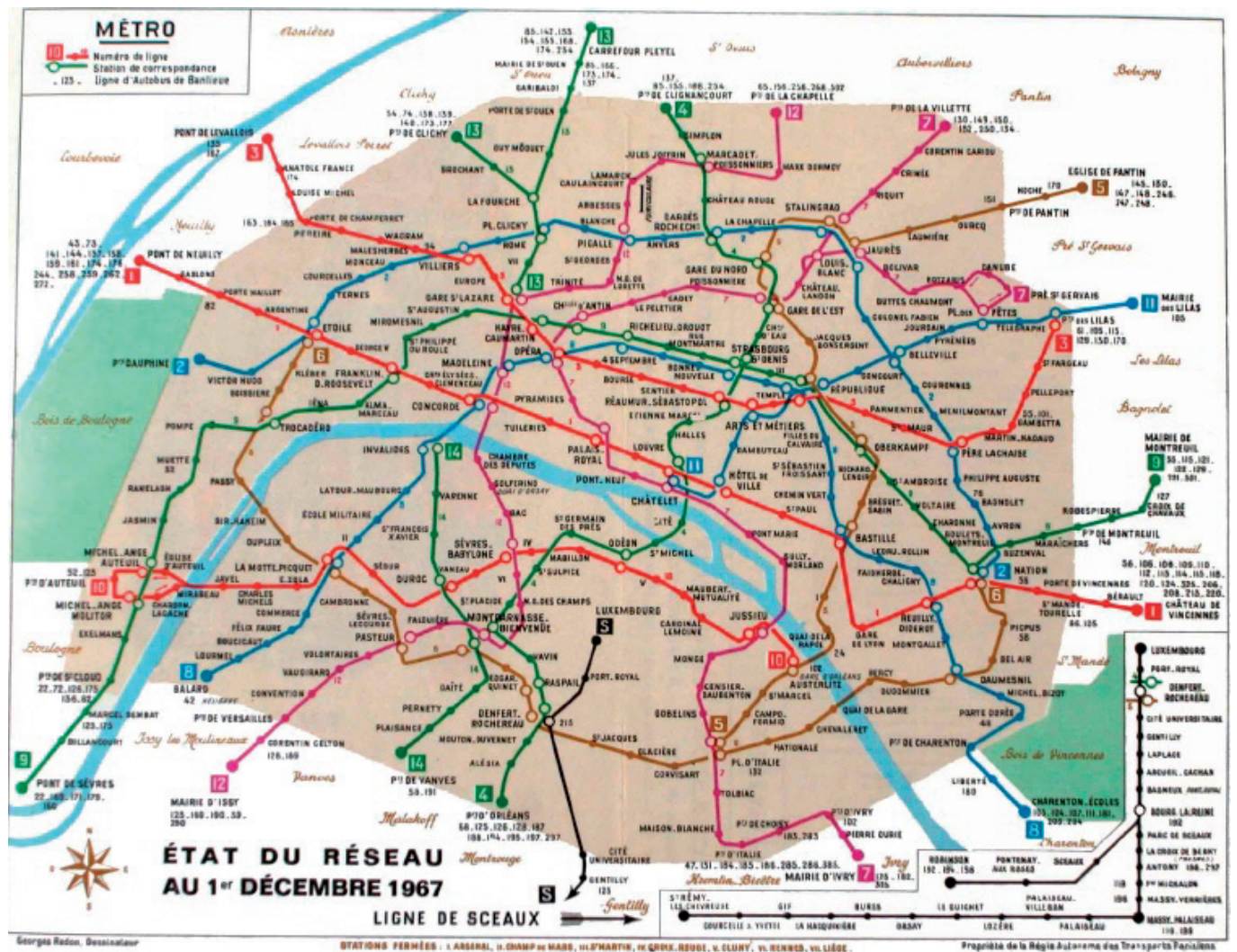


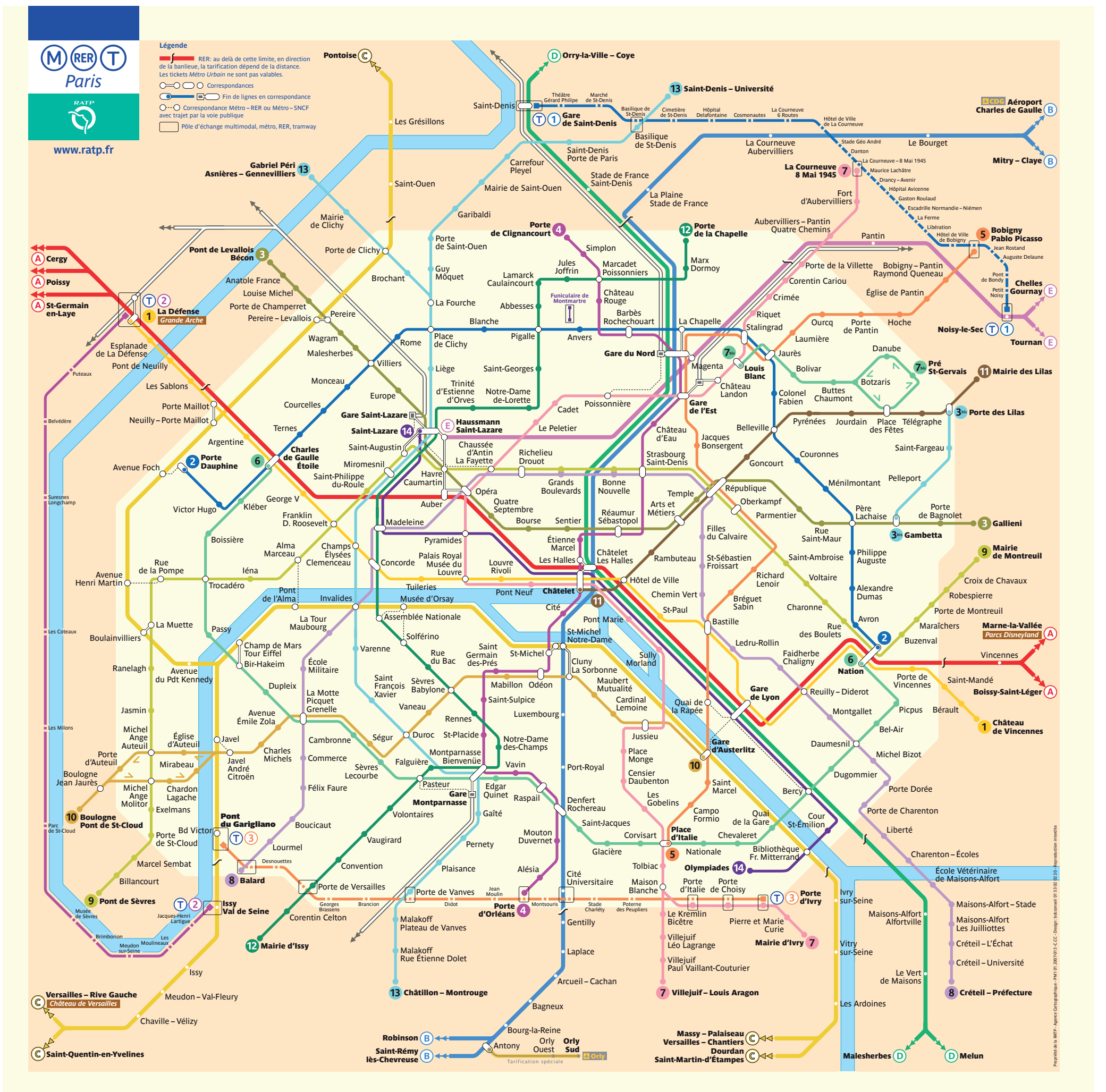
major avenues. Worse still, the map gave no clues to the additional complexities of the network. Not all services run at all times, and to find out exactly what routes might be available at any particular time of day, it was necessary to consult the small print: the detailed and complex service guide at the top of the map. New Yorkers' aversion to diagrammatic maps has entered design folklore, but the citizens of any city, faced with their metro network shown in this way, would object. The replacement, in 1979, was a semi-geographical map, and today's design is similar in concept and execution. It successfully uses colour to show the major service groups, and the grid-structure of the city itself goes some way to organising the network. However, there is no reason why a future design could not be diagrammatic, simplifying the line trajectories, clarifying Lower Manhattan, and emphasising the underlying structure of the system. For New York at least, octolinearity seems to match the structure of the network well, and it is the organisation of the network services themselves that puts the maps in difficulty.

Box 2 Paris: Testing Beck's rules to destruction?

Unlike London, by the 1930s the Paris Metro consisted of a very dense network of central lines with very little penetration into the far suburbs. They terminated at or near the historic city walls, with various suburban railways catering for travel needs beyond these. Unlike the Underground network, there was therefore never the same pressure to distort geography; the entire Metro could be mapped fairly clearly without any particular need to compress the suburbs and enlarge the centre. Furthermore, the routes of the lines themselves did not help to clarify the structure of the city. For example, the Metro's own ring (Lines 2 and 6) is too far from the centre to be able to define it in the way that London's Circle Line achieved.

The difficult problem with the Paris Metro was how to show the complex mesh of interconnected lines, the “vermicelli” as per Henry Beck's description [3] was not so much twisted as knotted (for example, see Montparnasse-Bienvenue to the south west). Despite this, a very successful clear geographical map was developed to show





the network, and it is far from certain that a Beck-rules design would have improved matters to any significant degree. In fact, in the 1940s and 1950s, Henry Beck himself discussed with the RATP the possibility of creating an octolinear diagrammatic map. Unfortunately, his prototypes were too distorting, showing Line 1 as a 45 degree diagonal, and tilting Paris on its side in the process [5, p. 67].

The creation of the RER network in the 1970s led to a rethink and the development of new designs, but the steady RER additions continually increased network complexity for many years. With a moving target, Paris Metro maps went through a period of unprecedented instability, as various designers grappled with the problem of showing the network diagrammatically,

but also without mimicking London design techniques too much [14]. The release of the 2000 design has marked a period of unusual stability, but this implementation is hardly ideal from a psychological perspective. Fourteen Metro lines, two Metro shuttles, five RER lines and three tramways is a lot to squeeze into a small space, and the resulting kinks (e.g., sixteen on Line 4, with an average of ten per Metro line) mask what little underlying structure the system has. The network therefore seems ideal for an all-curves approach, and this does improve its attractiveness and usability. The density of this network, and the highly intertwined lines, makes the design of good clear maps that reveal any underlying structure very difficult. Mapping the Paris Metro really is the search for the least bad solution.

[Top Left] Paris developed a successful, distinctive style of Metro Map from 1934 onwards. The complex network was tamed so successfully that the basic design lasted until 1971, making this style one of the longest lived of anywhere in the world.

[Above] Of all Paris Metro maps to date, the 2000 design follows Beck's rules most closely, but also demonstrates precisely why these rules can break down under certain circumstances. The lack of discriminability of line colours, for example at Gare du Nord, probably is not helping.

[Left] Using an all-curves approach, and focusing just on the parts of Paris that are of interest to tourists, it seems possible to improve the flow, clarity, and structure of the map. Usability studies show that journey planning with this design is at least 30% faster compared with the official version [11, 16].

Box 3 Madrid: Reinforcing Beck Folklore?

simbología

- Estación con horario restringido
 - Transbordo corto entre líneas de Metro
 - Transbordo largo entre líneas de Metro
 - Cambio de tren
 - Estación Cercanías-Renfe
 - Estación de ferrocarril de largo recorrido
 - Terminal de autobús interurbano
 - Aeropuerto Madrid-Barajas
 - Aparcamiento de disuasión gratuito
 - Aparcamiento de disuasión de pago
 - Centro atención al Cliente
 - Estación con acceso para personas con movilidad reducida / ascensor
- zona B1 B2 B3**
Cambio tarifario



MetroSur



líneas de Metro

- | | |
|------------------------------------|---------------------------------------|
| 1 Pinar de Chamartín / Congosto | 8 Nuevos Ministerios / Barajas |
| 2 La Elipa / Cuatro Caminos | 9 Herrera Oria / Arganda del Rey |
| 3 Villaverde Alto / Moncloa | 10 Hospital de Norte / Puerta del Sur |
| 4 Argüelles / Pinar de Chamartín | 11 Plaza Elíptica / La Peseta |
| 5 Alameda de Osuna / Casa de Campo | 12 MetroSur |
| 6 Circular | R Ópera / Príncipe Pio |
| 7 Las Musas / Pitis | |

[Above] Before 2007, the Madrid Metro map failed to capitalise fully on the benefits of schematisation. In reality it was an awkward compromise between a diagrammatic map and a geographical one.

[Right] From 2007, the map became uncompromisingly diagrammatic, but *tetralinear*. The designers reached this solution because of the requirement to produce a map that could be printed legibly at A5 size. With such a dense complex network, the only way this could be achieved was by eliminating all diagonals. However the flow of lines is inevitably disrupted by the many corners. Interchanges are also harder to configure at the lowest levels of linearity because there are only limited ways in which lines can intersect.

The Madrid Metro has been one of the success stories of the late 20th Century, with a rate of expansion that few other Western cities could even contemplate. As is often the case, this expanding network put existing cartographic techniques under pressure, leading to the adoption of a new solution.

Pre-2007 Metro Maps are typical of those devised for many networks. A diagrammatic approach has been adopted, but without any real understanding of how this can help the user, and hence how such maps should be designed so as to maximise their advantages. Hence, the centre has not been expanded as much as it could have been, leading to a tangle of lines, many interrupted by station names. In the suburbs, lines are kinked many times. Even if justified by reality, this is not information that is helpful to the passenger in any way. For example, it cannot really be used to locate the most appropriate choice of station, estimate journey duration, or be used to plan which route to take. Whenever a diagrammatic map imitates geography to this extent, at the expense of simplifying straight lines and other usability benefits, it is far from clear that it offers any advantages over a topographical map

The new map issued in 2007 has proved highly controversial. Its geographical distortion goes to the opposite extreme of its predecessor. It is also one of the very few maps to be produced that is *tetralinear*. The resulting corners give it a harsh appearance, and in several places interchanges are confusing, with lines entering and leaving symbols disjointedly, making their trajectories difficult to follow just where the map is at its most complicated. Ultimately, these problems stem from an optimistic size constraint.

Líneas

- 1 PINAR DE CHAMARTÍN / VALDECARROS
- 2 LA ELIPA / CUATRO CAMINOS
- 3 VILLVERDE ALTO / MONCLOA
- 4 ARGÜELLES / PINAR DE CHAMARTÍN
- 5 ALAMEDA DE OSUNA / CASA DE CAMPO
- 6 CIRCULAR
- 7 HOSPITAL DEL HENARES / PITIS
- 8 NUEVOS MINISTERIOS / AEROPUERTO
- 9 HERRERA ORIA / ARGANDA DEL REY
- 10 HOSPITAL DEL NORTE / PUERTA DEL SUR
- 11 PLAZA ELÍPTICA / LA PESETA
- 12 METROSUR

Simbología

- Estación con horario restringido
- Transbordo corto entre líneas
- Transbordo largo entre líneas
- Cambio de tren
- Estación pendiente de inauguración
- Metro ligero
- Estación de Cercanías-Renfe
- Estación de ferrocarril de largo recorrido
- Terminal de autobús interregional
- Terminal de autobús interurbano
- Terminales aeropuerto
- Parking
- Oficina de información al cliente
- Cambio tarifario



Plano esquemático de la red

