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Round in Circles and Back Again: Concentric Circles Maps Twelve Years On

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***Abstract*—this paper investigates schematic transit maps which are based upon concentric circles and spokes (*ortho-radial diagrams*). These have generated unprecedented levels of interest amongst the general public, with frequent calls by local media for official adoption. Many such maps have been designed, including Berlin, Paris and New York City. The focus here will be on two London versions created in 2013 and 2024. It is important to understand the appeal of such maps, design methodology and potential pitfalls. By considering criteria for effective design and also the outcomes of usability testing it is possible to identify circumstances where such maps can be considered as serious candidates for adoption.**

Keywords*—*schematic maps, transit maps, concentric circles maps, usability testing, history of schematic mapping

I. Concentric Circles Maps

Ever since schematisation techniques were first applied to urban rail maps in the early 20th century, designers have attempted to take advantage of these to highlight network structure with the intention of making systems easier to navigate and learn. The basic schematisation toolkit comprises omission of surface details, simplification of line trajectories, variable scale, local topographical displacement and linearisation [18, 21]. Using these, it is possible to depict lines using easy-to-recognise shapes and forms such as circles, ellipses, rectangles and horizontal or vertical axes (which can ground designs across the centre) [18, 23]. The process of shape-guided design has also recently become a topic of interest for researchers into automated computer-generation of schematic maps [2].

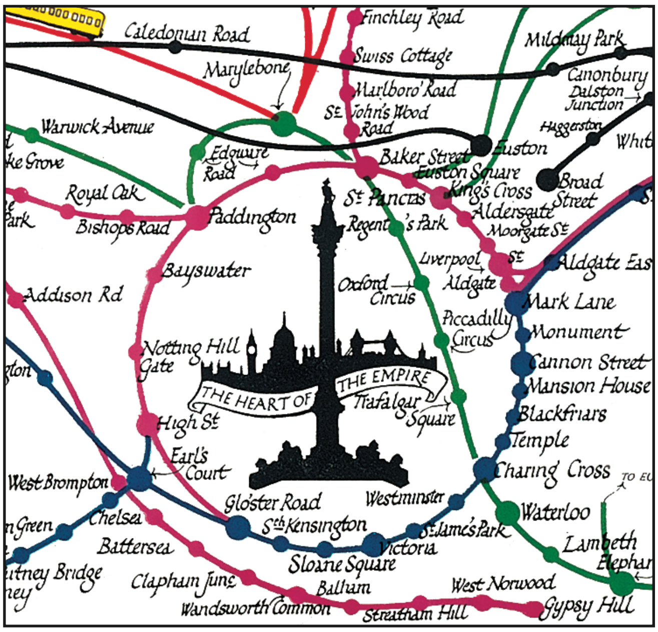


Fig. 1. The earliest map, known to the author, that depicts a perfectly circular line, was designed by Kennedy North in 1924. Its purpose was to assist people visiting the British Empire Exhibition.

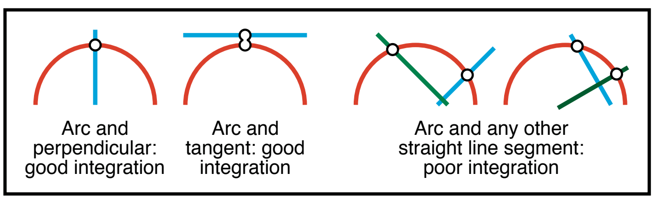


Fig. 2. The difficulties integrating circular arcs and straight lines.

One popular form that has been applied many times is used when a network has an orbital service. This has been depicted as a perfect circle, both on unofficial and official published designs, such as the London Underground (1924) (Fig. 1), the Berlin S-Bahn (1931) and also the Paris Metro (1938) [16, 18, 23]. Some attempts have been limited in their effectiveness because the designer expended the most effort into creating an orderly configuration of the circle line while neglecting the need to organise all of the other elements [23]. However, for a hybrid design comprising a circle plus linear depiction of the remaining lines, a balance is hard to achieve because arcs and straight lines can be difficult to integrate, as shown in Fig. 2 [24]. The result can be that straight-line elements cross curved ones at a multitude of different angles, resulting in an untidy, unaesthetic design and also, possibly, usability issues where angles are very shallow.

One solution to the problem of integration is to constrain the straight lines so that they all radiate from the centre of the circle. The result is that all crossings are perpendicular, contributing to the coherence of the design (see Section IIIA). This constraint also has the advantage that multiple orbital lines can be accommodated using additional circles (or arcs) all centred at the same point. A disadvantage with this methodology is the reduced flexibility in placing radial lines: This can result in topographical distortion and complex line trajectories (see Section IIIA). The earliest concentric-circles-and-spokes map (*concentric circles map* hereafter) appears to be a 1989 unpublished prototype for an integrated Berlin U- and S-Bahn map by Erik Spiekermann (Fig. 3). Published examples include a 2001 Lisbon bus map (Fig. 4) and a 2004 Paris Metro map from a tourist guide (Fig. 5), based upon concentric ellipses – presumably because the horizontal elongation was a better match for the shape of Paris compared with concentric circles [23].

Fig. 3. 1989 prototype concentric circles Berlin U- and S-Bahn map by Erik Spiekermann. The concept was intended to symbolise the newly-integrated city. Considerable revision would have been required once the *Ringbahn* had been refurbished and reopened.

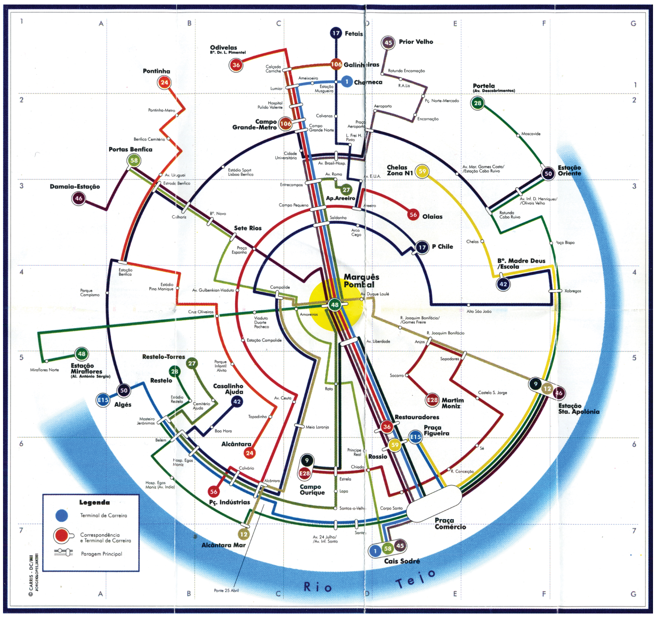


Fig. 4. Lisbon concentric circles bus map, 2001. The central point is a major roundabout/road intersection.

II. London Concentric Circles Version 1, 2013

Thus far, concentric circles maps comprised little more then a niche curiosity in the domain of schematic mapping. Knowledge of this methodology became more widespread after the author published, in 2013, a London Underground version. The impetus for this was the completion of a major rail project to create an outer-orbital rail loop in London (currently, the London Overground *Mildmay* and *Windrush Lines*). The loop had previously inspired two designers to create unofficial maps, each of these highlighting this development by showing it predominantly as a circle [20, 23]. Both designers utilised circles or circular arcs for some other routes but the remainder were straight lines at standard *octolinear* angles – horizontal, vertical and 45° diagonal straight lines, as used by Henry Beck for the first London Underground diagram published in 1933 [16, 22]. Both designs ran into difficulties integrating circular and straight line elements (Fig. 2) and also depicted the inner Circle Line (yellow on current Underground maps) as a perfect circle,

Fig. 6. Prototype London Underground map showing the difficulty with the inner-London Circle Line (yellow). Use of true spokes for its east and west extremities causes these to splay outwards. The path of the Overground loop (orange) is also shown and was prioritised to be a perfect circle for the 2013 concentric circles map (Fig. 7).

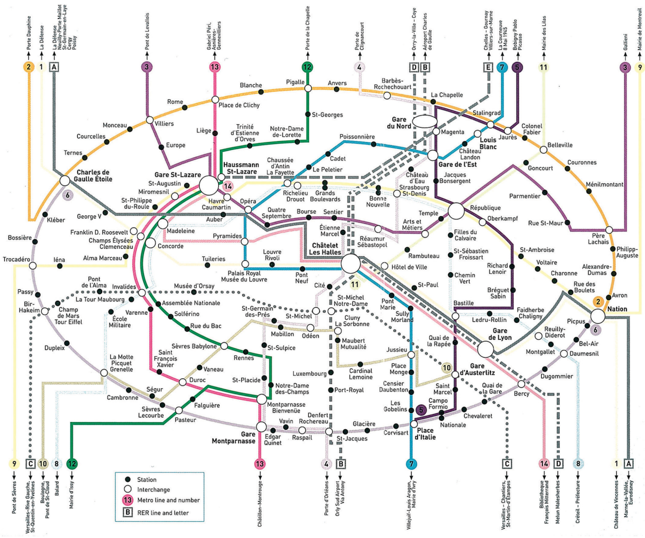


Fig. 5. Paris Metro map, 2004, from *art/shop/eat Paris*. There are four ellipse rings but most straight lines are not perpendicular to them.

resulting in considerable topographical distortion and lack of balance (see Section IIIA). This led the author to experiment with a concentric circles design as an intellectual exercise to see whether the identified weaknesses could be addressed by using a more rigourous methodology.

A. *Design Process and Priorities*

The primary decision for a concentric circles map is the location of the central point of radiation. An inappropriate choice can cause an unbalanced design, congested on one side and relatively sparse on the other. Tottenham Court Road was chosen, roughly midway between the sides of the Circle Line, and permitting the east-west-running Central and Elizabeth Lines (red and purple) to ground the design across the centre. From this choice, construction radiated outwards, attempting to keep the design compact. Unlike the previous designs, it was decided to prioritise a *perfectly* circular London Overground loop (orange in 2013). To avoid excessive topographical distortion in central London, there was no priority to configure a perfectly circular inner Circle Line. However, this constrained how the design rules could be implemented (Fig. 6). Strict use of spokes would give an unacceptable layout and this was addressed by relaxing the criterion, so that horizontal straight lines became permitted for eastern and western sides of the Circle Line. To maintain coherence, other lines in the vicinity of these were similarly depicted. In an attempt to reduce the complexity of line trajectories, other relaxations of the true-spoke criterion were exercised, resulting in straight line segments of lines that

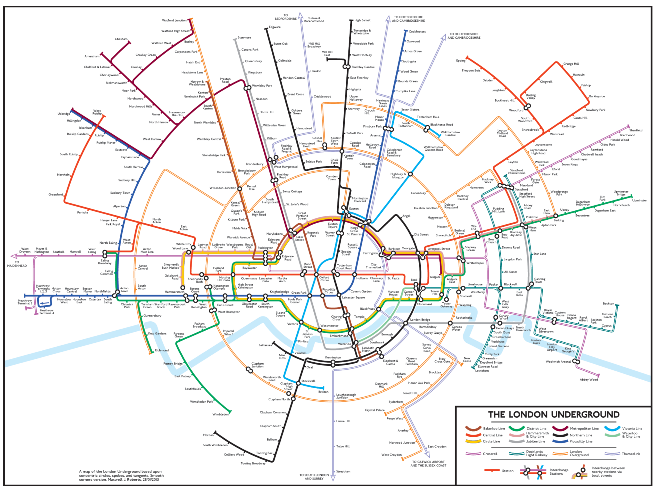


Fig. 7. London Underground concentric circles map, version 1, designed by the author. This is the original, as published in January 2013.

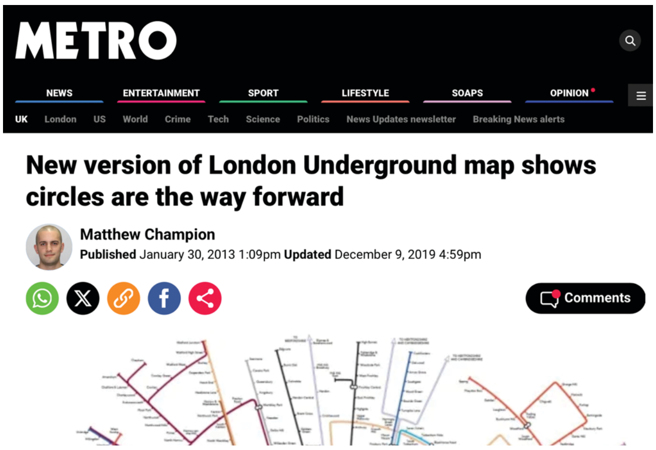
were tangents to curves (e.g., the Piccadilly Line, dark blue, at Holborn). Alternatively, some lines were angled to be in parallel with true spokes nearby. For example, the north London section of the Jubilee Line (grey) is parallel to the adjacent Northern Line Edgware branch (black). Hence, the final outcome (Fig. 7) became a loose implementation of the original design rules for a concentric circles map.

B. *Evaluation and Reception*

It is important to emphasise that the 2013 London concentric circles map was intended to be a *design study* rather than an attempt to create a map that might be a candidate for future implementation. The author has created many *design study* maps to explore and visualise alternative configuration methodologies, identifying the strengths and weaknesses of each in relation to the structures of the networks being shown [16]. For the London concentric circles map, the outcome demonstrated that it is possible to create a design for this city in this way, despite the network complexity. Simultaneously, it demonstrated that it is viable to apply the design priority of a perfect circular Overground loop. However, this does not show that an effective design has been created: Usability testing would be required for this. Furthermore, the original design rules had been relaxed, albeit in a principled manner. In the author's opinion, this weakened the overall aesthetics of the outcome.

More seriously, strict application of one design priority – a circular Overground loop – had resulted in topographical displacement in several locations, for example *Shoreditch High Street* erroneously placed adjacent to *Bethnal Green*, and *Camden Road* erroneously north of *Kentish Town*. Topographical distortion, in theory, is an entirely permissible component of the schematisation toolkit. In practice, this can lead to journey planning difficulties under certain circumstances (see Section IIIC). The displacements caused directly by the Overground loop additionally led the author to take a more relaxed attitude to similar levels of distortion elsewhere on the map to attain simpler line trajectories.

The map received considerable media and internet attention, much of it positive, with frequent assertions of improved clarity when compared with the official design [25]. There were many calls for its adoption (Fig. 8) despite the issues discussed earlier. In general, maps based upon unusual design rules receive lower usability ratings than more conventional ones [17, 21, 26]. Octolinear maps are regularly encountered worldwide and, hence, are much more likely to conform with people's expectations of how urban rail maps *should be* designed [14]. In the light of this, the strongly positive opinions expressed for the concentric circles map, greater than for any other design previously, took the author by considerable surprise.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New version of London Underground map shows circles are the way forward

Matthew Champion

Published January 30, 2013 1:09pm Updated December 9, 2019 4:59pm

Comments

Fig. 8. A typical headline from 2013 when the London concentric circles map, version 1, was published.

C. *Further Explorations*

With the positive response to the London concentric circles map, the author commenced further design studies to investigate the application of this methodology to other networks. The focus was on those with significant orbital lines. Highlights include the Berlin S- and U-Bahn map (Fig. 9) which, unlike the London version, fully adheres to the requirement that all straight lines radiate from the centre of the map. The design has been used in several usability studies (see Section IVA). The Paris Metro map (Fig. 10) depicts Lines 2 and 6 as a circle and is interesting to compare with the design based on concentric ellipses (Fig. 5). For the circular version, it was again possible to implement all straight lines as true spokes, giving it a more orderly appearance than the ellipses map but, conversely, the circular version has less balance, with adjacent regions of high and low station density that are not justified by actual topography (see Section IIIA). The problem for Paris is that the city is elongated east-west compared with north-south and, hence, is not necessarily suited to concentric circles. Also, to maintain compactness, the concentric circles map has non-topographical bends on the west side of Line 1 (yellow). The New York City Subway map (Fig. 11) is of particular interest because this network does not have a circle line, nor substantial orbital routes. However, the basic grid structure of the city enabled an outcome with clean, clear radial elements and relatively simple line trajectories yielding, perhaps, one of the most visually striking designs of all.

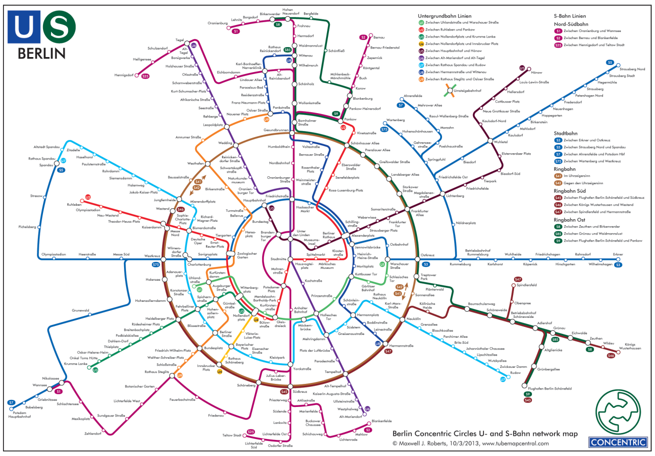

Fig. 9. Concentric circles map of the Berlin U- and S-Bahn networks, designed by the author in 2013. Unlike Spiekermann's map (Fig. 3) the by-now-reopened Berlin *Ringbahn* was the basis of this design.

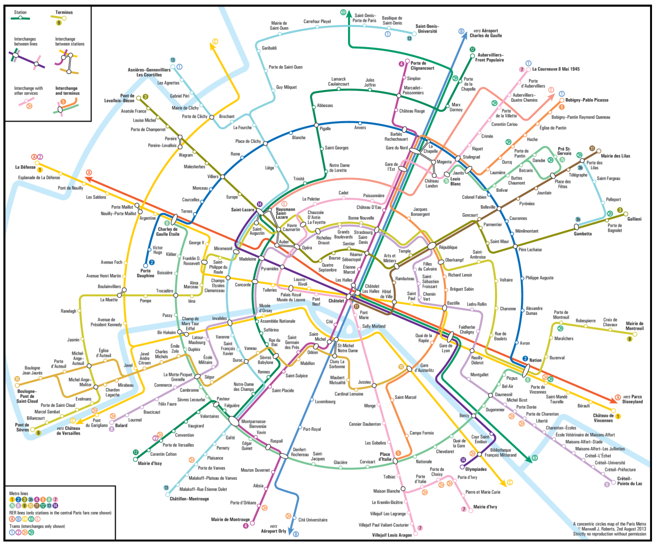

Fig. 10. Concentric circles map of the Paris Metro, designed by the author in 2013, depicting the orbital Lines 2/6 as a circle.

Fig. 11. Concentric circles map of the New York City Subway, designed by the author in 2013. Although no actual circles appear on this map, it is possibly one of the most visually powerful of all.

III. EFFECTIVE DESIGN AND CONCENTRIC CIRCLES MAPS

The flurry of interest generated by concentric circles maps, for a variety of networks, is striking and suggests that such designs are worthy of interest to researchers, both from usability and design perspectives. Indeed, there has been a number of investigations into the automated creation of such maps [1, 6, 35]. However, in order fully to understand their utility, it is useful to be able to ground their properties within some sort of usability framework that can be applied to schematic maps in general, so that their potential can be understood with reference to other schematisation methods.

A. Framework for Effective Design

Roberts [e.g., 16, 26, 27] has set out a framework for the effective design of schematic maps. This comprises five categories of criteria that should be optimised with respect to their configuration. The framework is not a *theory* in the sense that it merely identifies the important categories. It does not, for example, prioritise their various elements.

Simplicity. One important goal for the designer is to simplify line trajectories, making them easier to identify and follow. Roberts observed that the octolinear official Paris Metro map, introduced in 2000, fails to optimise by this criterion, so that the complex twists and turns of reality are translated into numerous zig-zagging bends on the map instead [28]. Reality has not been simplified, instead the shape of the complexity has merely been changed.

Coherence. This is a higher order, holistic criterion that concerns how lines should relate to each other to ensure that the overall design is well-organised and orderly with good shape. This can be achieved, for example, using symmetry, equidistance, parallelism and alignment.

Topographicity. Scale distortion and other forms of topographical displacement are permitted components of the schematisation toolkit. However, it is nonetheless desirable to avoid severe deviations because these can have genuine usability implications that are discussed in detail in Section IIIC. Hence, a map whose distortions cause undesirable side-effects would be said to have *poor topographicity* compared with maps without these defects.

Balance. There should be an even density of stations across the page: congested areas directly adjacent to sparse ones should be avoided unless this is necessitated by the topographical coverage of the network. A frequent balance issue occurs when an over-expanded centre results in highly compressed suburbs: The visually dense periphery draws attention away from the centre of the map.

Harmony. This refers to the overall aesthetics of the map. It is primarily a catch-all category for configural aspects that are visually pleasing but are unlikely to have measurable implications for usability. For example, equilateral triangles might be preferred to isosceles ones, and perpendicular crossings to those slightly off 90º. These aspects of the map will be more prone to individual differences in preferences than others, making this criterion difficult to optimise.

The most striking aspect of the framework is that, in many instances, there will be a conflict between optimising for *simplicity* of line trajectories versus *topographicity*. The trade-off between the two is the source of much of the variance in designs worldwide [14].

With the five framework criteria, the concentric circles maps, shown earlier, can be analysed systematically. All have high coherence owing to every circular arc being centred on the same point and, with the exception of the London version, every straight line radiating from this same centre. Hence, the London design has less coherence than the others, but is still high by this criterion. Conversely, the designs are questionable in terms of simplicity of line trajectories: Many urban rail lines have both orbital and radial components, plus lines that are difficult to categorise. The concentric circles approach requires all elements to be displayed as perfectly orbital or perfectly radial and this can result in the need for continual trajectory corrections. The New York City Subway map (Fig. 11), is the least problematic in terms of simplicity, arguably making this the strongest design so far.

Turning to topographicity, the issues with the London and Paris (Fig. 10) designs have already been noted and, for Paris, the topographical distortion – primarily owing to the inability to be able to elongate the map east-west compared with north-south – has also impacted on its balance. Again, the New York City Subway map fares better than the others by these criteria. In terms of harmony, only the London version has issues, owing to the need to compromise the design rules in order to prevent topographical distortion from becoming even more obtrusive.

The framework for effective design provides a useful tool for evaluating usability and it is important to note that not all concentric circles versions are equal in terms of fulfilling its five criteria. Usability, therefore, needs to be determined on a case-by-case basis and it would be a mistake to attempt to determine whether this design methodology succeeds or fails *en masse*. From the perspective of the designer, it is first important to identify underlying network structure on a city-by-city basis and then determine which design rules, of which concentric circles is just one solution, enable the best optimisation according to the five framework criteria.

When compared with octolinear designs, there is a potentially interesting dissociation. Concentric circles maps tend to have the more complex line trajectories. Conversely, their more regimented construction gives a more organised display of the network and, therefore, is likely to lead to greater coherence. This suggests that an appropriate usability study would give insights into the relative importance of the two criteria, as well as determining whether the initial enthusiasm generated by concentric circles designs is justified by actual data (see Section IVA).

B. *Visual Impact*

The impact of concentric circles maps seems to go beyond what might be expected from their organised, regular structures yielding high levels of coherence, and it is worth speculating on how other aspects of their construction might influence their reception.

From a high-level cognitive perspective, such maps give an overt message that they have been painstakingly designed with precision, adding appeal for people who appreciate this level of craftsmanship. Contrast this with the curvilinear map of the Paris Metro (Fig. 12). This consistently outperforms the official octolinear version on an objective measure of usability: the time needed to plan complex journeys between pairs of stations [26, 28]. Despite this, the popularity and ratings for this design do not reflect its advantage and, although such maps are not trivial to create, the effort necessary to address the framework for effective design is not immediately salient from their appearance.

At a lower level, there are distinct tendencies for people to prefer curvature [4]. This particularly manifests itself for abstract objects [7] although there are substantial individual differences. This preference has been shown for schematic maps where, for non-octolinear designs, curvilinear maps consistently receive higher ratings for their attractiveness, but not their usability, compared with alternatives [17, 26]. Combining the general preference for curves with a desire for orderliness in the context of journey planning, this potentially accounts for the strong, positive initial responses to concentric circles maps.

Going beyond conceptual and aesthetic judgements, the construction of a concentric circles map, with a strong centre and radiating lines, potentially creates artificial perspective and a vanishing point. This can assist in fixating attention at the centre and visually perceiving the image [5, 8]. However, this perspective effect might also trigger the sensation of falling into a tunnel. Depending on the individual, this could be dynamic or induce visual discomfort. Potentially, this could explain why a small number of people express very negative reactions to these maps.

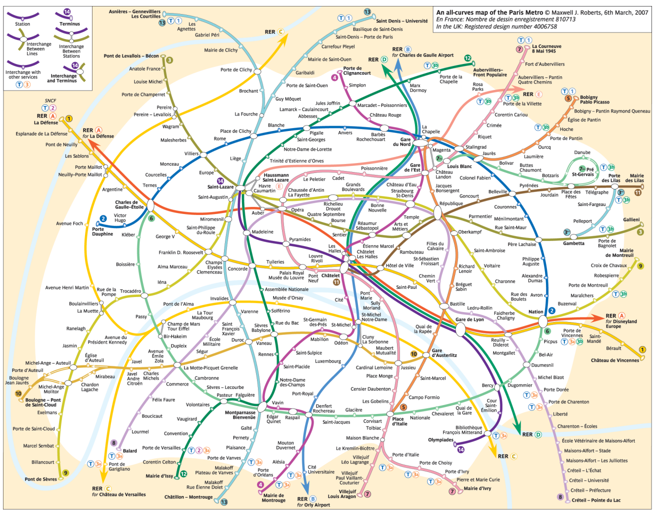

Fig. 12. Curvilinear map of the Paris Metro, designed by the author in 2007. Although this consistently outperforms the official octolinear version [26, 28] it appears less 'designed' than alternatives.

C. *The Importance of Topographical Distortion*

Although many users express no concerns regarding topographical distortion [9], this can, nonetheless, generate a number of usability issues for some people. These may apply irrespective of design rules but the qualities of concentric circles maps often result in topographical layout issues that are very difficult to resolve, especially if challenging design priorities have been adopted (Section IIB). Hence, designers need to be aware of how usability might be damaged so that only benign distortion is implemented.

Configuration affects journey choice. Many people plan journeys as though the layout of a schematised map is providing information about distance and speed, hence the preference for shorter, more direct routes implied by the map even if topographical reality deviates from this [10, 11, 15, 30, 33, 34]. Hence, a map whose line configurations represent pragmatic compromises that were made by the designer, rather than travel hints, can cause misdirection. Where concentric circles maps necessitate complex line trajectories, or greatly exaggerated distances, it is important to ensure that these will not deter people from choosing the most efficient routes (Section IVA).

Configuration should not conflict with mental models. Even if maps are impeccably configured so that the most efficient routes are always implied, it is still possible that there will be conflicts with people's expectations, i.e. their beliefs about the organisation of a city compared with that depicted by a map. Deviations might cause discomfort or rejection of the design. Research has identified individual differences in how people make sense of the topographical implications of schematised maps [3] with at least three different interpretations (Fig. 13). Hence, irrespective of the intentions of the designer, at least some users are likely to be disturbed by conflict. Expectations can also be created by the maps themselves: users can have their mental models of a city distorted by schematised maps [12, 32]. To mitigate against conflict, care should be exercised at different levels, for example, (1) the relationship between a city and satellite regions such as airports; (2) the relative positions of districts within a city; and (3) the configurations of nearby stations within a district. The London concentric circles map (Fig. 7) has a number of problems with respect to (ii) and (iii), but the official pocket London Underground map (Fig. 24) has topographical issues at all three levels.

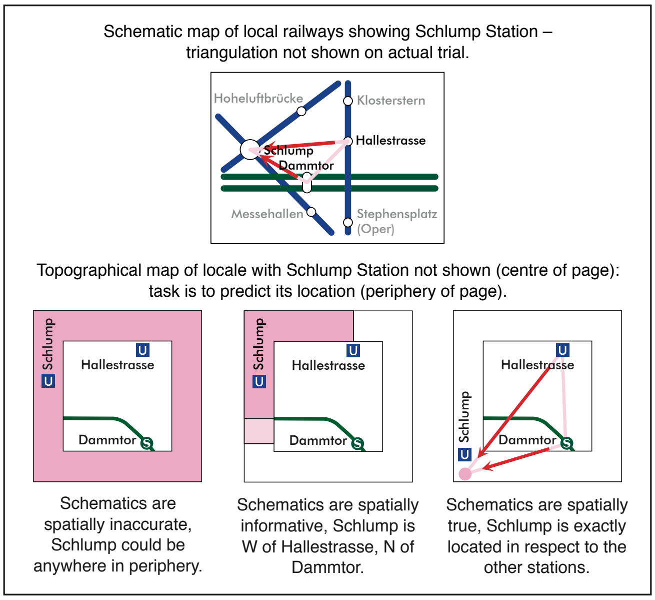

Fig. 13. Three strategies for interpreting schematised maps identified by Berendt *et al.* [3]. People who interpret schematic maps as being correct representations (right) would experience the most conflict.

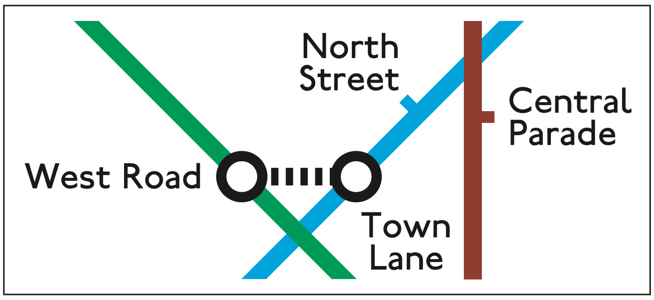

Fig. 14. The importance of respecting implicit topography. A short walk interchange is explicitly shown between Town Lane and West Road stations. From this diagram, at least some users will (1) expect to walk eastwards to get from West Road to Town Lane; (2) will assume that it is also a short walk from Town Lane to North Street; and (3) might even assume that North Street and Central Parade stations are nearby. Ideally, to prevent any map-induced navigation errors, all of these inferences should be correct.

Implicit topography should be respected. If schematised maps acknowledge any surface topography, then this will necessitate anticipating user inferences. For example, if a river or a park is shown then stations that, in reality, are near to these features should be shown as adjacent on the map. As another example, many transport undertakings now advertise transfers between nearby disconnected stations via local streets. Where these are offered, the linked stations should be placed nearby on the map. Ideally, the length of the walking connection should be relatively short so that other interchanges are not implied by similar or shorter distances between stations in the same area (Fig. 14). In theory, local signage should be sufficiently clear such that users do not need to make inferences from the map about which direction to travel from one station to another. In practice, there is no consensus amongst designers as to whether relative positions of stations should be preserved, but spatial information is probably more important for nearby stations than distant ones. Complete reversals, such as inverting a north-south relationship, should be avoided if possible. This is an issue for a number of station arrangements on the 2013 London concentric circles map.

Relevant topography should not be compromised. If an incorrect station is chosen to visit a park or cross a river then this is merely an annoyance. Neglect of other topographical details might have serious consequences. One example is fare zones. These usually reflect the topographical distance of stations from the centre. The display of these zones, therefore, becomes an important issue in situations where there is both topographical distortion *and* the network has a complicated fare structure. This can add considerably to visual clutter as well as causing navigation difficulties if it is important to determine route-fare validity. Conversely, the appearance of the fare zones themselves can indicate the extent to which there is excessive topographical distortion and this will be discussed in more detail in Section VB.

IV. Subsequent Developments

A. User Testing

Given the positive responses to concentric circles maps, an important next step was to commence usability testing to see whether these were justified. Broadly, maps can be investigated *objectively* by giving people tasks that require using them, such as planning a journey between designated stations. The time needed for this can be recorded, along with any errors made. The journey itself can be analysed to see whether an efficient one has been assembled. *Subjective* evaluations can also be investigated by asking people to rate various aspects of the usability of maps, along with choosing which designs they would prefer to use. These give more systematically analysable data than social media ‘likes’.

A typical concentric circles map will have high coherence and poor simplicity. In contrast, a well-optimised octolinear design will have lower coherence but better simplicity. In such a circumstance, differences in the usability and ratings between maps will be revealing. It has also been suggested that the high coherence of concentric circles maps, reflecting their better organisation, might have an impact on learning the underlying structure of a network [13, 27]. However, this is a difficult outcome to investigate for a complex network if people have experienced a design for mere tens of minutes in a usability study. Hence, the initial focus was directly on ease of use rather than the by-products of use.

For the first study [27], the Berlin concentric circles map was chosen for testing (Fig. 9). The reasons for this included: this map implemented concentric circles and true spokes with no deviations; there were no issues with balance or harmony; many Berlin lines are unconnected, giving a large pool of plausible, but difficult (two interchanges necessary), journeys to plan; and there was an already-available direct octolinear comparison (Fig. 15), optimised for simplicity of line trajectories. Volunteers for user testing planned series of journeys between designated station pairs across Berlin, one set of journeys for one of the maps and a different set for the other. Measures of map effectiveness included (1) how long journeys took to plan; (2) whether errors were made; and (3) estimations of journey durations if implemented. Because all of the volunteers experienced both maps, this enabled an analysis of which design was better for each individual. After experiencing both maps, people were asked to rate their agreement with a series of statements about the usability of each, for example, *lines were easy to follow for this map: strongly agree/agree/neutral/disagree/strongly disagree.* The scores on these statements were aggregated together to give a total rating score for each design.

Surprisingly, given the enthusiasm the concentric circles map had previously received [25], it was comprehensively defeated on both objective and subjective measures [27]. The octolinear version was more likely to be chosen as the preferred design for everyday use, received higher scores on the rating task, *and* enabled people to plan journeys faster. People had been asked to give written statements concerning their likes and dislikes about the two maps and, interestingly, many complained that the concentric circles map made every journey look roundabout. Hence, from the journey options that they could identify, it was hard to choose the fastest, most direct looking route.

To test the above complaint, a *route choice* task was next investigated [19, 29]. People were presented with sequences of trials in which origin/destination stations were connected

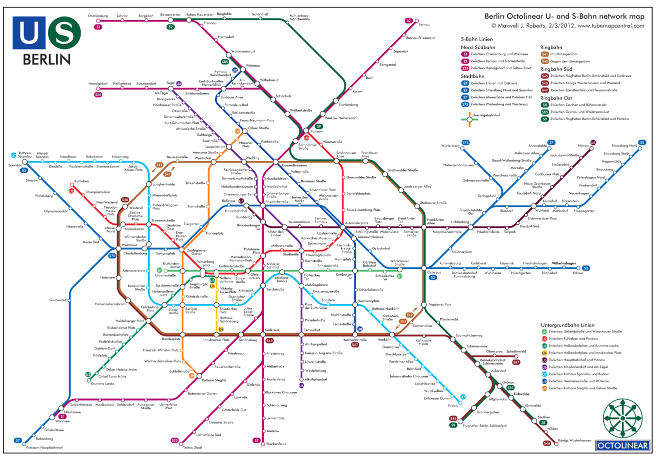

Fig. 15. Octolinear map of the Berlin U- and S-Bahn networks, designed by the author in 2012. This was included in usability studies as a comparison with the concentric circles version (Fig. 9).

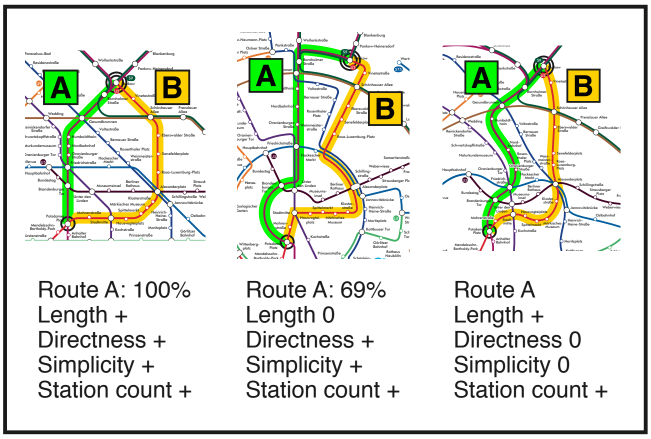

Fig. 16. Examples of route choice items in which people were asked to identify which option they believed to be fastest. Two are items from the usability study [29]: an octolinear trial (*left*) and the matched concentric circles trial (*centre*). For comparison, the same trial is also shown applied to a spatially representative map (*right*). According to the BVG online journey planner, Option A is, indeed, the faster (16 versus 22 minutes). Hence, the concentric circles map is potentially misleading. The main source of the actual difference in journey times is almost certainly the number of intermediate stations (8 versus 12). This was *not* the primary metric used by people in determining route choice in this study.

by predetermined pairs of highlighted routes (Fig. 16). The task was to identify the option that the volunteers predicted would be the fastest. If the previous complaint was correct, and identifying effective routes was harder for the concentric circles map, then it would be expected that decision times would be longer for the concentric circles map compared with the octolinear design. Also, for at least some concentric circles map trials, less consensus as to the fastest option would be expected. As before, all people made decisions for both maps. After the route choice task, people completed a statement rating task to give quantitative measures of their usability opinions for the two designs.

It was shown that route choice decision time was, indeed, a valid measure of difficulty in identifying best candidates for the fastest routes: times were significantly greater for trials where there was no clear consensus. However, there was no evidence of disproportionate prevarication for the concentric circles design [29]. It was still the less-preferred of the two, despite this, and received lower statement rating task aggregate scores, although less adverse than previously. Interestingly, two additional questions had been added to the statement rating task that directly related to route choice, and the concentric circles map scored particularly low ratings on these: People continued to believe that the route choice task was disproportionately the more difficult for the concentric circles map, even though not supported by the objective data.

Overall, the results of the studies can be pieced together as follows: Concentric circles maps induce positive initial responses but, when people actually plan journeys using these (and choose between self-generated route options), this quickly switches to strongly adverse usability ratings [27]. However, ratings become less adverse when *only* choosing between alternative journey options. This suggests that *route generation* is putting people in difficulty, rather than *route choice* [29]. It is an open question whether this is because (1) people have issues with the actual assembly of a route, or else (2) they can assemble routes easily but, because these lack *plausibility* (Fig. 16), this causes additional attempts to find alternatives. Both explanations predict an increase in journey planning times compared with the octolinear design, as was observed in the first study [27].

In Section IIIA, it was suggested that the usability of concentric circles maps cannot be evaluated *en masse* because the versions perform differently according to the five criteria for effective design. However, all such designs have circular arcs as a substantial component, by definition, and so all are potentially amenable to the same issues as identified for the Berlin map [27, 29]. The root cause of these problems appears to be the presence of complex line trajectories potentially reducing the directness and, hence, plausibility of candidate routes.

In broad terms, the results of usability studies suggest that, when configuring a map, *coherence* of line organisation should *never* take priority over *simplicity* of line trajectories themselves. This takes us back to the original suggestion that concentric circles maps should not be adopted without good reason. As for all schematisations, it is crucial to match the design rules to the network structure so that all framework criteria can be optimised, not some at the expense of others.

B. *Further Explorations*

Three further designs, by the author, developed the theme of matching design rules to network structure, for example, by confining the design of concentric circles maps to cities for which this methodology is well-suited, or modifying the design rules to make them more compatible with a particular city structure. The first investigation was for Köln, whose historic street plan itself is based upon concentric circles and spokes (Fig. 17). In previous usability studies, people had

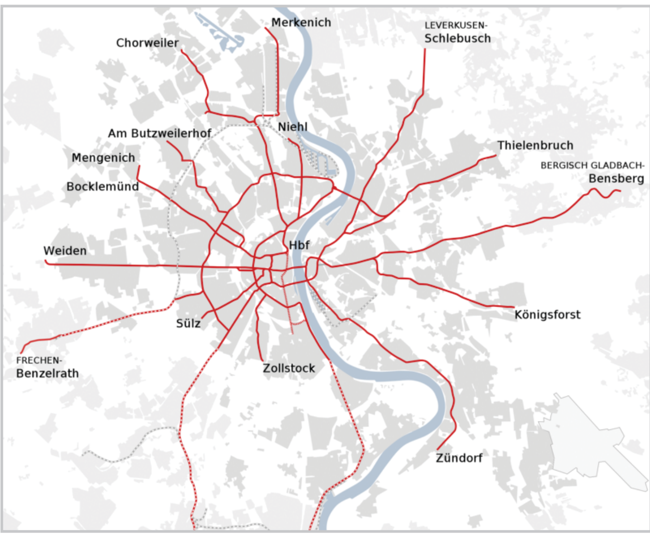

Fig. 17. Map of Köln showing the topographical layout of the tram lines. The distinctive structure of the city is readily apparent.

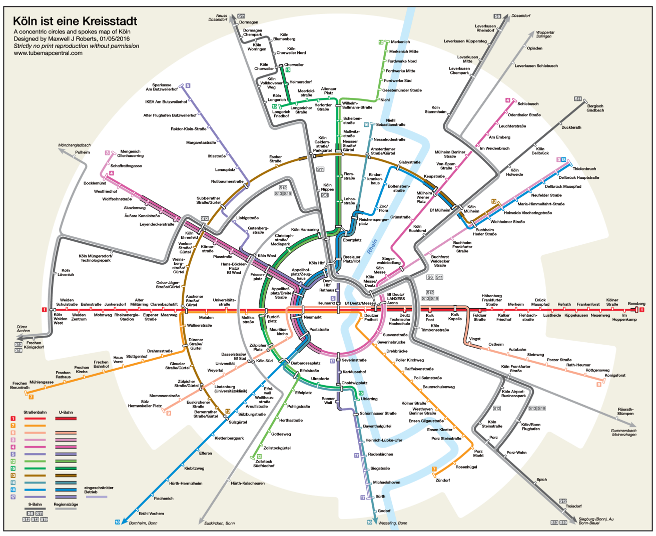

Fig. 18. Concentric circles map of Köln designed by the author in 2016. This map merely enhances the structure that is already present.

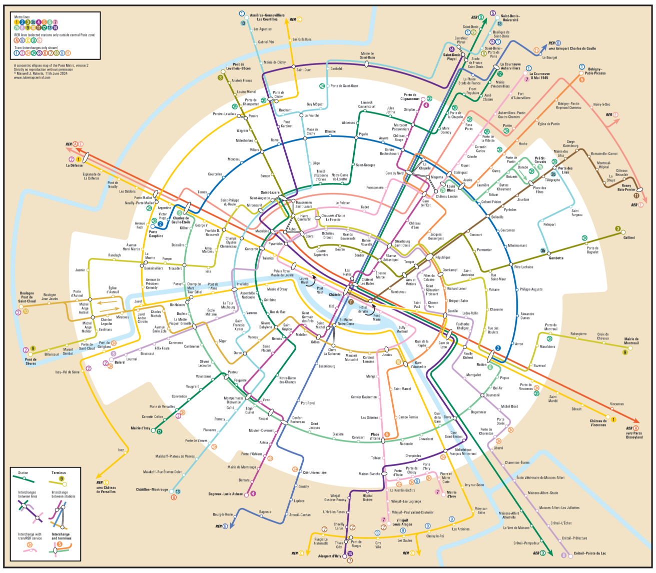

Fig. 19. Concentric ellipses map of the Paris Metro, designed by the author, updated 2024 to show they latest extensions. Suitably straighter, the east-west axis dominates the design.

expressed a dislike for concentric circles maps owing to the implied indirectness of journeys [27]. In contrast, the Köln map matches the natural lines of communication very closely indeed, with minimal potential for misleading configurations and conflict with mental models (Fig. 18).

An alternative approach was taken for Paris in 2017. Taking inspiration from the 2004 design in Fig. 5, concentric ellipses were investigated as a method to make the design proportionally correct (Fig. 19). This version was difficult to construct because spokes radiating from the centre would not be perpendicular to the ellipses. Hence, each straight line had to be configured individually to attain this. The design only achieved partial success because, for perfectly concentric ellipses, as size increases, the length of the major axis relative to the minor axis proportionately reduces. As a result, the east-west elongation of the map is still not quite sufficient. Despite this, it was possible to implement a perfect, straight Line 1 trajectory on the west side of Paris.

Returning to New York City (Fig. 11), the map suggests, perhaps paradoxically, that the effectiveness of a concentric circles design might depend on a strong radial structure – several lines converging directly towards the centre – rather than the presence of orbital elements. The Moscow Metro is, therefore, another good candidate for this methodology, and the outcome does not contradict this supposition (Fig. 20).

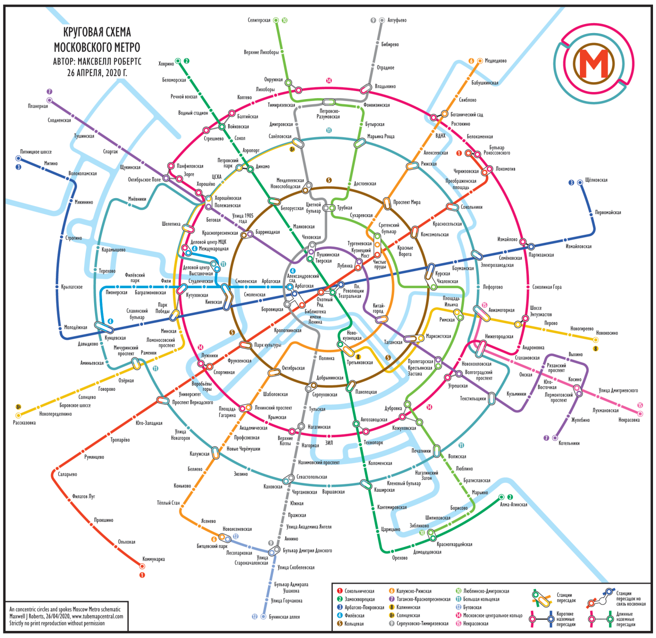

Fig. 20. Concentric circles map of the Moscow Metro, designed by the author in 2020. There are three circle lines but, nonetheless, the structure of the network is strongly radial.

C. Background Events

Other events suggested that concentric circles maps were capturing the attention of transport undertakings. Notably, in 2022, KVB, the operator of Köln transport, officially adopted a design (Fig. 21) that was derived from the author's own configuration (Fig. 19). In 2024, TfL created a concentric circles map of the London Underground, although this was primarily intended as an advertisement gimmick – for a mobile phone company – rather than for navigation (Fig. 22). The topographical distortion renders it almost unusable. In contrast, the concept is also used to publicise the *Superloop* bus network (Fig. 23) although, with not all stops shown, the potential for using this for navigation is limited. Unfortunately, the official London Underground map itself has not received the same attention. The last major update for the pocket map was in 2020, receiving Thameslink services, then the Elizabeth Line (2021) and, since 2024, new colours for the Overground lines (Fig. 24). Despite the latest additions, it has maintained the same dimensions as the first London octolinear network schematisation, published in 1933 and designed by Henry Beck [22]. Quite apart from basic legibility, with hundreds of additional stations, this has resulted in numerous usability issues [16, 31] and the design

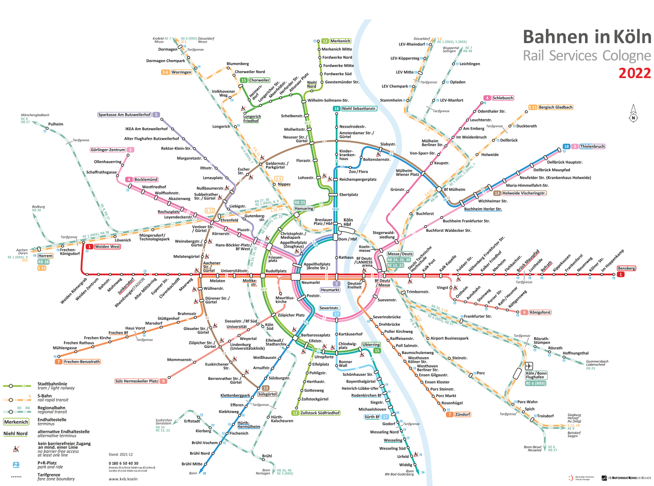

Fig. 21. Official map of the Köln network, based on the author's own configuration (Fig. 18).

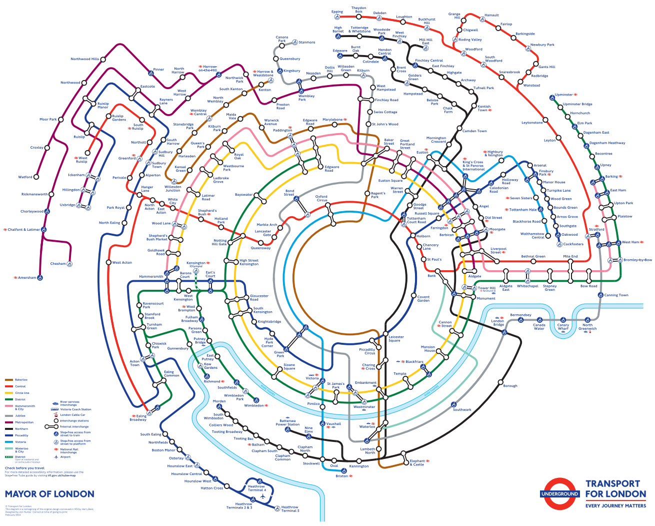

Fig. 22. Concentric circles and spokes map of London Underground lines, published by TfL in 2024. Not all straight lines are true spokes.

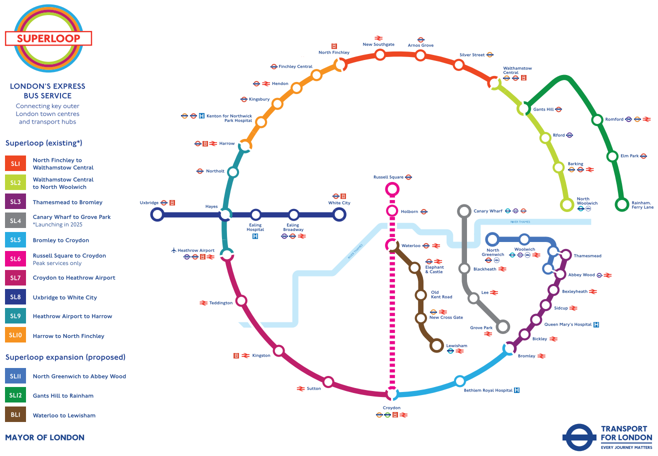

Fig. 23. TfL map of Superloop buses, 2024. Many proposed additions to the network will add yet more concentric arcs and also spokes.

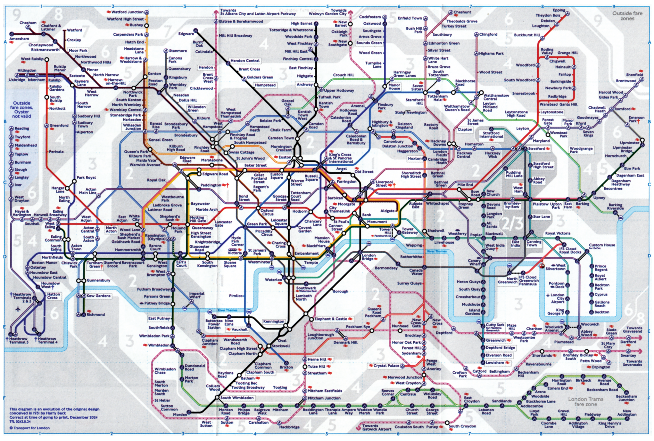

Fig. 24. Official TfL London Underground pocket map, 2024. The design is now so congested and cluttered that navigation is difficult.

fails, simultaneously, simplicity, topographicity, and balance criteria for usability. Lack of space limits the opportunities for coherence which, even if possible, would be buried by the complex line trajectories. Focusing on topographical distortion, there are many severe displacements including, for example, relative positions of nearby stations (Fig. 26). This, in conjunction with showing interchanges that involve walking between disconnected stations, has set up many opportunities for erroneous inferences (see Fig. 14) [24]. West London is so compressed that it is unlikely to comply with the mental model of this region by any user.

V. London Concentric Circles Version 2, 2024

With the continuing interest in concentric circles maps, particularly for depicting transport in London, and coupled with lessons learnt from previous design studies and usability testing, this seemed an appropriate point in time to revisit the London concentric circles map of 2013.

A. New Design Priorities

A decision was made to start afresh with a completely new design. The map would include all lines and services shown on the official London Underground map. To

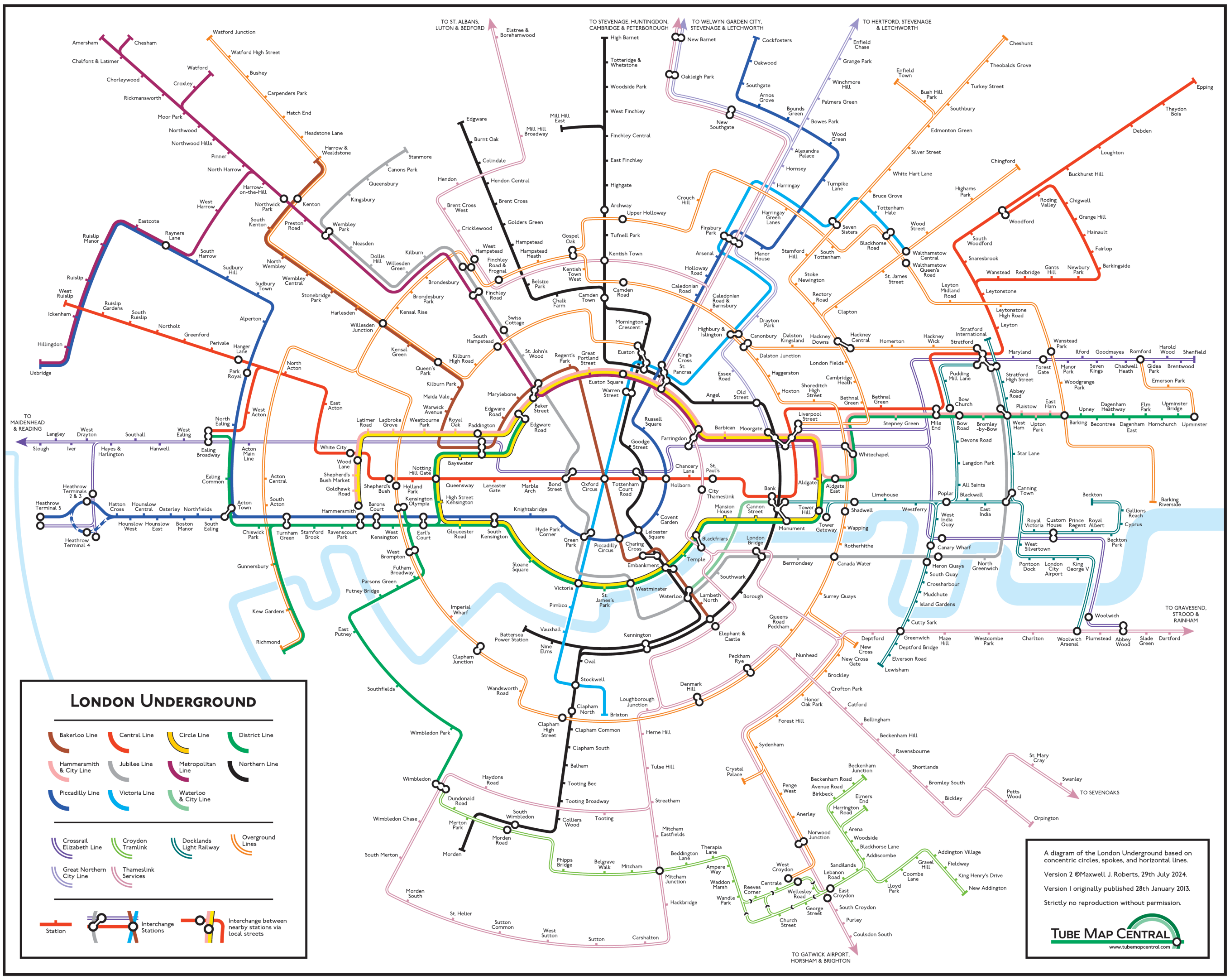

Fig. 25. London Underground concentric circles map, version 2, designed by the author in 2024.

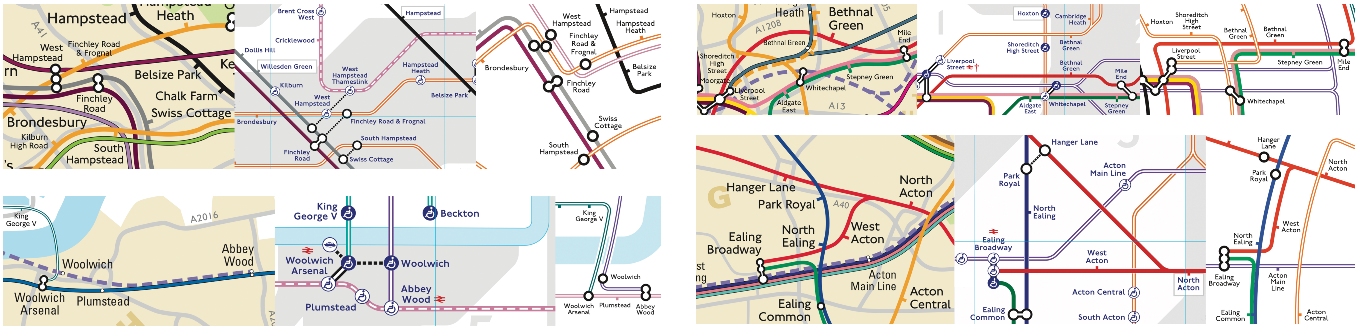

Fig. 26. Examples of micro-layout displacements on schematised maps of the London Underground. In each case, the leftmost map is topographically accurate, the centre map is the 2024 official station poster, and the rightmost map is the 2024 concentric circles design. *Top left: Finchley Road area;* On the official map, the interchanges of West Hampstead and Finchley Road are particularly lengthy, leading to the issues illustrated in Fig. 14. Also, note the exaggerated distance between Finchley Road and Hampstead on the official map. A short bus ride would be far faster than a trip on the Underground between the two. On the concentric circles map, it was necessary to rotate the West Hampstead interchange by 60º approx. but the relative station locations and distances between them have been preserved. *Top right: Liverpool Street to Bethnal Green area;* The official map incorrectly shows Shoreditch as nearer to Bethnal Green than Liverpool Street and also positions the two Bethnal Green stations north-south rather than east-west. Shoreditch is appropriately displayed on the concentric circles map. Density of lines prevented exactly relative positions at Bethnal Green, but the east-west relationship is correctly shown. *Bottom left: Woolwich area;* unnecessary over-compression on the official map renders the interchange between the Woolwich stations as implausible. *Bottom right: Acton area;* On the official map, the positioning of Acton Main Line compared with West Acton is reversed. Also, note the relative positions of the between Hanger Lane and Park Royal.

emphasise that the new version was not merely an update, Oxford Circus was chosen as the central point (as opposed to Tottenham Court Road previously). This also permitted improved symmetry in the centre. Revised design priorities would also be adopted to address previous failings.

Topographicity. The first objective was to create a map more spatially representative of London than the 2013 version and that would be topographically superior to the official octolinear design. Instead of a circular Overground loop, which would distort topography excessively, the priority was to configure clusters of nearby stations such that their relative positioning and distance would be spatially informative and not entirely contradicted by reality. A topographical map of London railway lines was consulted frequently to ensure that this would be the case.

Coherence and Harmony. The difficulties with using true spokes to depict the Circle Line remained (Fig. 6) and so the requirement for using these was relaxed for its east and west protrusions, plus east-west running lines at similar latitudes. However, north and south of these, all straight lines would be true spokes. To improve optimisation further, true spokes were quarantined from non-spokes and straight lines were never permitted to intersect. As additional measures: (1) arc radii and spoke angles were replicated for line elements at different locations, where possible, to enhance coherence; and (2) within all the constraints, every attempt was made to maintain the simplicity of line trajectories and the balance of the design.

B. *Evaluation and Reception*

The new version is shown in Fig. 25. Overall, it proved possible to satisfy all the new design priorities, particularly the intention to confine non-true-spoke straight lines to the middle latitudes of the map. Hence, compared with the 2013 design, the objectives to improve coherence and harmony were satisfied. Topographicity is also considerably improved. However, these attainments come at the expense of more complex line trajectories, especially in north-west London.

The assertion that topographicity is enhanced is difficult to quantify in a simple way because global variable scale and local displacements are independent and cannot combine easily to give a single topographicity index. Instead, micro-layout features have been highlighted that demonstrate the differences in station topographical displacement between maps (Fig. 26). This does not demonstrate that one design is superior to the other, but at least emphasises the issues that can face a designer. In contrast, the application of fare-zones can identify issues at the macro-layout level (Figs. 27 and 28, see also Section IIIC). On the official map, the complexity and disorganisation of the fare zone borders are a side-effect of topographical distortion. In contrast, simpler borders were attainable on the concentric circles map. Fare zones are also shown for an alternative octolinear design by the author (Fig. 27). This was created with similar topographical priorities to the concentric circles map and, likewise, shows simpler fare zone borders compared with the official version: Difficulties showing them are *not* an inherent property of octolinearity.

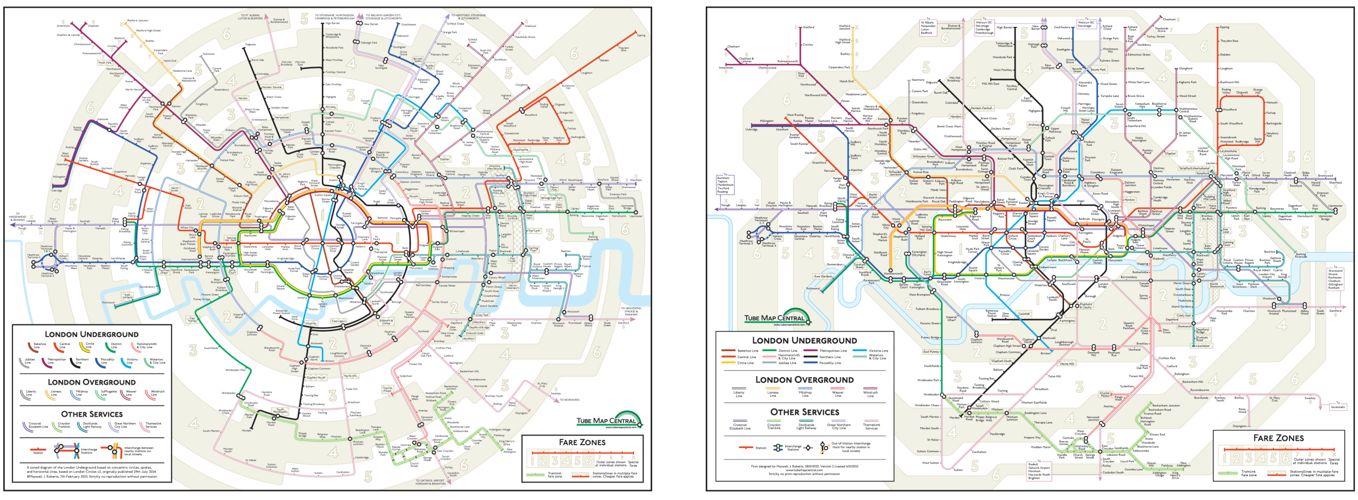

Fig. 27. *Left:* 2024 concentric circles map with fare zones applied. *Right:* 2020 octolinear map, designed by the author, also showing fare zones.

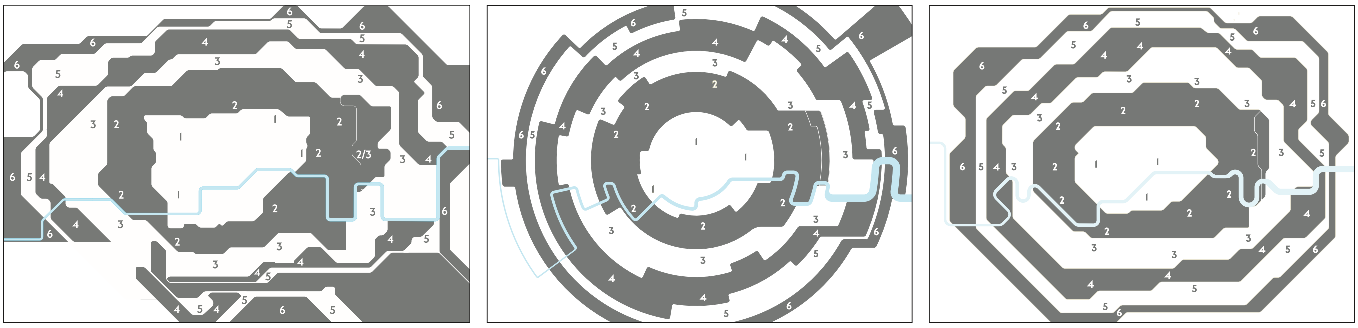

Fig. 28. Fare zones extracted from (*left*) the 2024 official station poster London Underground map (which differs in several places from the pocket version in Fig. 24), (*centre*) the 2024 concentric circles map and (*right*) the 2020 octolinear map designed by the author (Fig. 27).

The response by the general public and media to the 2024 London concentric circles map was, if anything, even more strongly positive than for the 2013 version. For example, an initial post on the social media platform, ***X***, quickly secured over 2800 reposts and 18,000 'likes'. To some extent, this enthusiasm might reflect the decline in effectiveness of the official design, so that the response to the concentric circles map, at least in part, was owing to a general desire for improvements that might, for example, be satisfied by an enlarged and reconfigured official octolinear design.

VI. Conclusions: Are Circles the Way Forward?

Concentric circles maps present a very different visual representation of urban rail networks compared with more conventional octolinear designs and many people express positive dispositions towards them. However, these are not valid criteria from the point of view of assessing usability. The caveats identified as a result of user-testing the Berlin version [27, 29] very much potentially apply to concentric circles representations of other cities, such as the London version of 2024. There is, therefore, every possibility that, after experience at attempting to plan journeys using any concentric circles map, ratings of the design will decline, as indicated by the patterns of results obtained for the Berlin version (Section IVA).

The key to understanding the utility of concentric circles maps is the simplicity of line trajectories and, hence, the compatibility of network structure with this methodology. Complex line trajectories on a map are a symptom of a poor match between network structure and its design rules – but this applies to all maps, not only those that use concentric circles and spokes. Where simplicity is poor, any gains from coherent aspects of the design will not compensate for more basic failings. For concentric circles maps with complex line trajectories, users will have difficulty generating plausible routes and may be misled into selecting less efficient ones (Fig. 16). This would also be the case for a map using any other design rules mismatched with network structure, and/or poorly optimised for simplicity.

Past research indicates that, for maps with identical design rules (e.g., octolinear or curvilinear), the complexity of line trajectories predicts user ratings of both attractiveness and usability [17, 26]. It is therefore a plausible hypothesis that subjective *and* objective measures of usability will be most favourable for concentric circles maps with the simplest line trajectories. Such research has not yet been performed but would be a useful means to identify baseline disposition towards these, independently of implementation. It would also be useful for further research to address the speculation that high coherence of a design results in better learning of network structure [13, 27], with the proviso that the results of research conducted so far point towards the likelihood that complex line trajectories will bury the underlying network structure no matter how coherently presented this is: learning would be strongest for maps with simple line trajectories.

Official use of concentric circles designs is not ruled out. One category of best-candidate cities is those whose actual structure is based upon concentric circles and spokes. Köln has already been identified as one such location (Figs. 17, 18 and 20). Another possibility is Amsterdam (Figs. 29 and 30) [13]. In both cases, the inherent properties of the natural lines of communication match the design rules closely, leading to

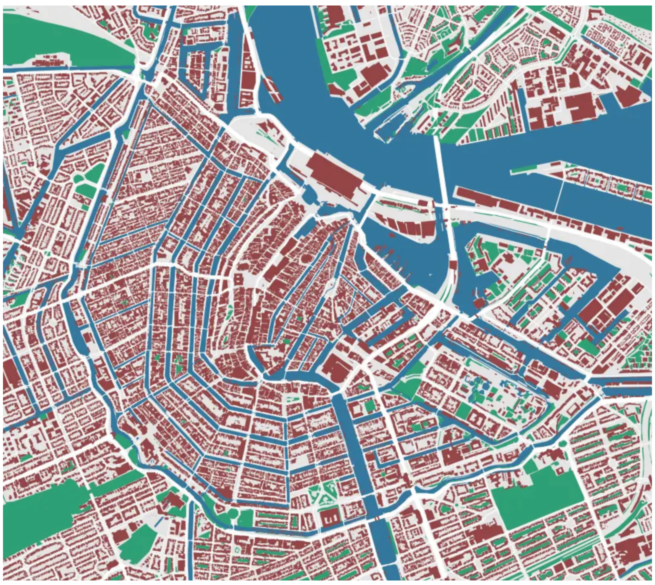

Fig. 29. Satellite view of Amsterdam showing the concentric inner city. The outskirts shift more towards a grid structure and this suggests that a hybrid concentric-grid design might be the most appropriate.

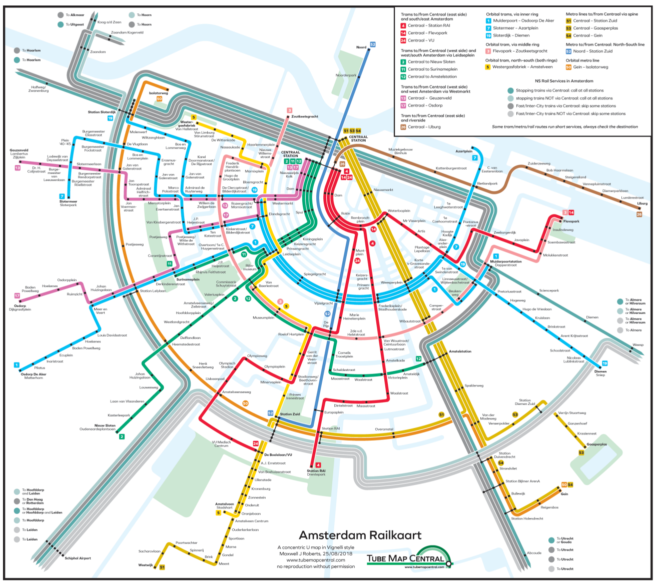

Fig. 30. Concentric U-s map of Amsterdam rail services designed by the author in 2018. Nieuwmarkt was chosen as the centre: At any other location it would be impossible to show the inner canal rings.

minimal scope for topographical distortion and conflict with user mental models, and also yielding line trajectories whose complexity reflects reality. Speculatively, the other category of suitable cities is those with a highly radial structure, such as Moscow (Fig. 20), even for networks without a substantial orbital component (e.g., as per New York City, Fig. 11). User testing would be necessary to investigate this.

Another factor that needs to be accommodated into an evaluation of the utility of concentric circles maps is individual differences in user preferences and beliefs about usability [17, 21, 26]. Informal internet surveys indicate that around 40% of respondents disliked the 2024 London concentric circles map on initial presentation. Catering for individual differences is a considerable challenge for designers and transport undertakings. If an individual rejects a map and uses computer journey planners instead, then the design has failed no matter how impeccable its usability. Short of providing multiple designs so that users can choose their favourites, the best defence against this is probably to match design rules with network structure and ensure that all five criteria for the framework for effective design are optimised, then demonstrate the underlying soundness of the creation with usability testing.

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