**References**

[1] Shanmukhappa, T., Ho, I.W.H., Tse, C.K., Leung, K.K., 2019. Recent development in Public Transport Network Analysis From the Complex Network Perspective. *IEEE Circuits and Systems Magazine*, vol. 19, no. 4, pp. 39-65, Fourth quarter 2019, doi: 10.1109/MCAS.2019.2945211.

[2] M. Kurant and P. Thiran, “Extraction and analysis of traffic and topologies of transportation networks,” *Physical Review E*, vol. 74, no. 3, pp. 1–10, 2006.

[3] C. Von Ferber, T. Holovatch, Y. Holovatch, and V. Palchykov, “Public transport networks: Empirical analysis and modeling,” *The European Physical Journal B*, vol. 68, no. 2, pp. 261–275, 2009.

[4] Sienkiewicz et al, 2005. Statistical analysis of 22 public transport networks in Poland

[5] Xu et al., 2007. Scaling and correlations in three bus – transport networks of China

[6] Chen et al., 2007. A study on some urban bus transport networks

[7] Soh et al., 2010. Weighted complex network analysis of travel routes on the Singapore public transportation system. Physica A

[8] London et al., 2015. Complex network analysis of public transportation networks: A comprehensive study

[9] Shanmukhappa, T. et al., 2018. Spatial analysis of bus transport networks using network theory. *Physica A*

[10] Zhang et al., 2018. A review and prospect for the complexity and resilience of urban public transit network based on complex network theory. *Complexity*,

[11] Regt. R., Ferber, C.O., 2018. Public transportation in Great Britain viewed as a complex network

[12] Feng et al., 2016 Empirical study on a directed and weighted bus transport network in China

[13] Chatterjee et al., 2016. Statistical analysis of bus networks in India, Plos One

[44] Iseki, H., & Taylor, B. D. (2009). Not all transfers are created equal: Towards a framework relating transfer connectivity to travel behaviour. Transport Reviews, 29(6), 777–800.

[45] Litman, T. (2008). Valuing transit service quality improvements. Journal of Public Transportation, 11(2),

[46] Wardman, M. (2004). Public transport values of time. Transport Policy, 11(4), 363–377.

5 Discussions and Conclusions

The results of proximity densities, proximity average distances and most used infrastructure presented in Section 4 facilitated a direct comparison of operational characteristics of the HCMC bus network under two commonly used approaches for PT network analysis, the topological network and the temporal network. To the best of our knowledge, such an apple-to-apple comparison of results from the two approaches has not been reported in the literature. Below are key points from our comparison.

* The temporal network approach, while more computationally demanding both in terms of the size of the final representation of the real bus network and the computing power to carry out the analyses compared to the topological approach, was inherently able to capture the temporal heterogeneity and intra-day variation of a PT network operation. Examples of such heterogeneity were stop to stop travel time along directed routes and changes of their headway throughout the day. One implication in our study was that the shortest path travel time in the temporal network included both transfer time and in-vehicle time, instead of only in-vehicle time in the topological network.
* Results from both approaches showed similar qualitative trends. For example, bus stops close to the city’s northern border could only reach 90% of other stops for a total travel time of over 90 minutes (see Figure 4). Meanwhile on average an inner city stop was reachable by the highest number of other bus stops for a travel time between 30-60 minutes (see Figure 5). Both approaches came up with visually similar corridors of most traversed bus stops (in terms of shortest paths between stop pairs across the network, see Figure 9).
* The results from topological network tended to be larger than those from the temporal network in all metrics calculated, including the proximity densities (in all travel time categories except for the ‘60-90 minutes’, see Figure 6), the proximity average distance in all travel time categories (see Figure 8) and the number of stop pairs that have their shortest path passing a given bus stop (see Table 1). By design topological network approach (at least with L-space graphs) was not suitable for picking out most used bus routes in connect stop pairs in the network (via their shortest paths).

Results from temporal network analysis revealed insights into the HCMC bus network operation from a perspective not previously reported. Key findings included that

*Limitations*

*Future work/Further improvements*

**Notes to changes in Introduction**

In this work, we build on the temporal network methodology [50] to model time-dependent operation of the bus network in Ho Chi Minh City (HCMC), Vietnam, and to target three research objectives. The first objective was to identify pieces of infrastructure (e.g. bus stops and bus services) that would be critical to maintaining the network connectivity and their changing with time as a result of the time-dependent bus operation. The importance of a bus stop in this study is measured by a simplified version of its betweenness centrality. Such insight would be highly valuable in deciding node ordering for maximising impacts of targeted attacks in studying network robustness, especially if those attacks were to happen consecutively at irregular points in time and the node ordering reevaluated after each attack. The temporally changing accessibility across the network will also be investigated. Second, different to the majority of existing research in which accessibility was evaluated for a given origin-destination pair, in this study we measure the accessibility of a bus stop by the number of bus stops in the network reachable to (or from) that bus stop within a given time period, e.g. under 30 minutes, from 30 minutes to 60 minutes, from 60 minutes to 90 minutes, and over 90 minutes. Finally, this study aims to statistically quantify the differences of the above network metrics calculated by a topological network model (using an L-space graph) and by a temporal network model. To the best of our knowledge, such comparison has not existed in the literature. ~~and would provide evidence of potentially missing information when modelling PT operation as a temporally static network.~~

**Notes on paper 1**

* Below is a list of routes that have end stops (either first or last) that are outside of HCMC and thus removed.
* Also note that route 70-5 was excluded because it has only 2 stops, one at the boundary of HCMC, the other outside of HCMC (see the bottom of the below output list)
* Bus routes DL01 and 72-1 would be mostly used by tourists rather than the general public, thus were excluded from this analysis.
* The water bus route WB01 is more suitably classified a ferry service than a traditional bus service, thus was excluded in this analysis
* The new metro line, which was yet operational at the time of this study, was excluded in this analysis.

<https://www.theverge.com/2019/10/14/20909422/dell-xps-15-7590-2019-review-oled-core-i9-specs-features-price>

route 5\_0, 05

[7208, 334, 335, 336, 338, 337, 340, 339, 341, 343, 342, 344, 346, 345, 348, 347, 349, 350, 353, 351, 355, 352, 358, 354, 359, 356, 357, 360, 361, 362, 363, 364, 365, 366, 368, 367, 369, 373, 370, 374, 371, 372, 378, 375, 377, 376, 379, 381, 380, 383, 382, 89, 90, 385, 384, 387, 386, 388, 390, 389, 392, 391, 393, 395, 397, 137, 138, 139, 8]

route 5\_1, 05

[8, 2393, 2, 3, 5, 279, 281, 282, 283, 284, 285, 286, 288, 3164, 287, 290, 289, 292, 242, 291, 294, 296, 293, 295, 298, 297, 300, 299, 302, 301, 305, 304, 309, 306, 310, 312, 307, 308, 314, 316, 311, 313, 318, 315, 320, 317, 322, 319, 321, 323, 325, 324, 330, 327, 329, 332, 331, 333, 7208]

route 81\_0, 60-1

[7208, 1186, 1188, 1187, 572, 574, 4559, 500, 1101, 1102, 1103, 2142, 2143, 339, 341, 342, 344, 346, 345, 348, 347, 2348, 2345, 2349, 2350, 2351, 2352, 2355, 2354, 976, 965, 977, 966, 969, 2775, 2776, 2777, 2778, 2779, 2781, 2254, 2250, 2252, 1926, 1921, 1928, 1922, 1930, 1932, 1927, 1934, 1929, 1937, 1931, 1939, 1941, 1933, 1935, 1789, 1788, 1791, 1790, 1792, 1794, 1795, 708, 712, 709, 714, 710, 716, 713, 725]

route 81\_1, 60-1

[725, 630, 631, 632, 633, 634, 635, 1856, 1854, 1857, 1858, 1861, 1863, 1865, 1893, 1886, 1887, 1895, 1888, 1898, 1892, 1900, 1894, 1902, 1896, 1904, 1897, 1899, 1908, 1910, 1903, 4489, 2342, 2341, 2344, 2677, 2676, 3811, 2678, 2680, 932, 935, 933, 936, 942, 937, 944, 2356, 2359, 2360, 2364, 2362, 2368, 2365, 315, 320, 317, 322, 319, 321, 323, 325, 328, 324, 2083, 2084, 1040, 1041, 1042, 396, 536, 537, 1919, 1097, 1098, 1100, 1099, 7208]

route 215\_0, 60-2

[7280, 1186, 1188, 1187, 572, 7014, 576, 574, 2145, 500, 394]

route 215\_1, 60-2

[394, 1042, 396, 536, 537, 1919, 1097, 1098, 1100, 1099, 7280]

route 82\_0, 60-3

[7213, 1186, 1188, 1187, 572, 576, 574, 398, 4392, 401, 1113, 1111, 1112, 410, 413, 412, 414, 7011, 415, 416, 417, 418, 419, 420, 421, 299, 302, 301, 305, 361, 1403]

route 82\_1, 60-3

[1403, 362, 363, 364, 365, 366, 476, 473, 475, 478, 480, 479, 482, 481, 485, 1025, 1030, 1026, 1028, 494, 498, 495, 536, 537, 1919, 1097, 1098, 1100, 1099, 7213]

route 83\_0, 60-4

[7215, 1186, 1188, 1187, 572, 7014, 576, 574, 4560, 4559, 398, 4392, 401, 7013, 1113, 1112, 410, 413, 414, 415, 416, 417, 418, 419, 420, 421, 423, 299, 302, 301, 305, 361, 1403]

route 83\_1, 60-4

[1403, 362, 363, 364, 365, 366, 476, 473, 475, 477, 478, 480, 479, 482, 481, 485, 483, 1025, 1030, 1026, 1028, 494, 7159, 495, 7215]

route 85\_0, 61-1

[7216, 334, 335, 336, 338, 337, 340, 3385, 4555, 3387, 3386, 3388, 3389, 3391, 6983, 493, 490, 492, 497, 1502, 1504, 1495, 1497, 1499, 1506, 1501, 1508, 1503, 3390, 3395, 4131, 3392, 3396, 3393, 4229, 3397, 3394, 3399, 3398, 3400, 3402, 3401, 3364]

route 85\_1, 61-1

[3364, 3363, 3365, 3366, 3368, 3369, 3367, 3370, 3372, 3373, 3375, 3374, 3377, 1533, 1530, 1535, 1532, 1537, 1534, 1536, 1539, 1538, 402, 403, 404, 405, 3376, 3378, 3379, 3380, 3382, 3383, 3381, 330, 327, 329, 332, 331, 333, 7216]

route 86\_0, 61-3

[7257, 3362, 3360, 2348, 2345, 2349, 2347, 2350, 2351, 2353, 2352, 2355, 2357, 2354, 976, 964, 965, 977, 966, 969, 972, 2775, 2776, 2777, 2778, 2779, 2781, 2780, 2254, 2250, 2251, 2252, 166]

route 86\_1, 61-3

[166, 2342, 2341, 2346, 2344, 2677, 2675, 2676, 2678, 2680, 932, 935, 933, 936, 942, 937, 938, 944, 2356, 2359, 2358, 2360, 2361, 2364, 2362, 2363, 2368, 2365, 3403, 3405, 7257]

**route 87\_0, 61-4**

[7217, 3874]

**route 87\_1, 61-4**

[3874, 7217]

route 88\_0, 61-6

[7214, 3362, 3360, 349, 350, 353, 351, 355, 352, 358, 354, 359, 356, 357, 360, 361, 362, 363, 364, 365, 368, 367, 369, 373, 370, 374, 1189, 1192, 79, 76, 7270, 35]

route 88\_1, 61-6

[35, 1451, 27, 7265, 1256, 32, 31, 1092, 1093, 1094, 1095, 1096, 293, 295, 298, 297, 300, 299, 302, 301, 303, 305, 304, 309, 306, 310, 312, 307, 308, 314, 316, 311, 313, 3403, 3405, 7214]

**route 89\_0, 61-7**

[7591, 1310]

**route 89\_1, 61-7**

[1310, 7591]

route 90\_0, 61-8

[7214, 3362, 3360, 2348, 2345, 2349, 2347, 2350, 2351, 2353, 2352, 2355, 2357, 2354, 976, 964, 965, 977, 966, 969, 972, 2775, 2776, 2777, 2778, 2779, 2781, 2780, 2091, 2056, 3415, 3414, 3417, 3416, 3419, 3421, 3418, 3420, 272, 169, 174, 2454, 2651, 2920, 2921, 3101, 3100, 3103, 2504, 2505, 2521, 1927, 1934, 1929, 1937, 1931, 1939, 1941, 1933, 1935, 1860, 1862, 1864, 2929, 2928, 2930, 2906, 3423, 2385, 2384, 2386, 2934, 2389, 2391, 713, 725]

route 90\_1, 61-8

[725, 630, 2306, 7141, 2308, 2309, 3404, 2909, 2908, 2910, 1963, 1966, 1968, 3161, 1892, 1900, 1894, 1902, 1896, 2447, 2446, 2451, 3153, 3156, 3155, 2915, 2919, 2457, 2916, 271, 7027, 3407, 3406, 3409, 3408, 3411, 3410, 3412, 3413, 2092, 2052, 2677, 2675, 2676, 3811, 2678, 2680, 932, 935, 933, 936, 942, 937, 938, 944, 2356, 2359, 2358, 2360, 2361, 2364, 2362, 2363, 2368, 2365, 3403, 3405, 7214]

route 204\_0, 62-1

[7136, 3427, 3428, 3429, 699, 698, 701, 700, 703, 3431, 3432, 702, 704, 705, 706, 711, 708, 712, 709, 714, 710, 716, 713, 119, 4149, 140, 718, 715, 720, 717, 724, 719, 721, 723, 722, 464, 8]

route 204\_1, 62-1

[8, 621, 620, 622, 624, 625, 623, 627, 628, 629, 1386, 117, 116, 630, 631, 632, 633, 634, 635, 636, 637, 638, 639, 640, 3422, 3430, 641, 643, 644, 645, 646, 3876, 3424, 3425, 7136]

route 92\_0, 62-10

[7219, 3427, 3428, 3429, 699, 698, 701, 700, 703, 3431, 3432, 702, 704, 705, 706, 711, 708, 712, 709, 714, 710, 716, 713, 119, 4149, 140, 718, 715, 720, 717, 724, 719, 721, 723, 722, 464, 8]

route 92\_1, 62-10

[8, 621, 620, 622, 624, 625, 623, 626, 627, 628, 629, 1386, 117, 116, 630, 631, 632, 633, 634, 635, 636, 637, 638, 639, 640, 3422, 3430, 641, 643, 642, 644, 645, 646, 3876, 3424, 3425, 7219]

route 93\_0, 62-11

[7263, 3116, 3119, 3118, 3121, 3120, 3123, 3122, 3125, 3124, 3127, 3126, 3128, 3129, 3131, 3130, 3133, 3132, 3136, 3134, 3137, 3135, 3139, 3138, 2247, 2244, 2246, 2248, 2249, 496]

route 93\_1, 62-11

[496, 2148, 2149, 2151, 2150, 2153, 3019, 3020, 3021, 3023, 3025, 3024, 3026, 3027, 3028, 3029, 3030, 3031, 3032, 3033, 3034, 3035, 3036, 3038, 3039, 3040, 3041, 3042, 4421, 7263]

route 94\_0, 62-2

[7220, 3434, 695, 694, 697, 696, 3435, 699, 698, 701, 700, 703, 3431, 3432, 702, 704, 705, 706, 711, 708, 712, 709, 714, 710, 716, 713, 119, 4149, 140, 718, 715, 720, 717, 724, 719, 721, 723, 722, 278]

route 94\_1, 62-2

[278, 621, 620, 622, 624, 623, 626, 627, 628, 629, 1386, 117, 116, 4150, 630, 631, 632, 633, 634, 635, 636, 637, 638, 639, 640, 3422, 3430, 641, 643, 642, 644, 645, 646, 647, 648, 649, 650, 651, 3433, 7220]

route 95\_0, 62-3

[7209, 3928, 3930, 3929, 3925, 3926, 3927, 3932, 3931, 732]

route 95\_1, 62-3

[732, 7617, 5826, 3917, 3918, 3921, 3919, 3920, 3922, 3923, 7209]

route 97\_0, 62-5

[7209, 2276, 3967, 2225, 2223, 2267, 3964, 3944, 2274, 3956, 3940, 3943, 3952, 1395, 4759, 1230, 1232, 4588, 1231, 1235, 1233, 1234, 1236, 3635, 4490, 1237, 1238, 1239, 166]

route 97\_1, 62-5

[166, 4669, 1115, 1116, 1117, 1151, 1689, 1152, 1154, 1153, 1156, 1155, 1158, 1160, 4592, 1157, 4586, 1162, 1164, 1161, 2259, 2268, 2261, 3954, 3950, 3953, 3951, 3974, 2224, 3945, 2222, 3949, 3939, 2265, 2227, 3941, 7209]

route 214\_0, 62-6

[7209, 3436, 3437, 3438, 3439, 3440, 3441, 3442, 3443, 3444, 3311, 3313, 3312, 3446, 3445, 3448, 3447, 3450, 3449, 2381, 2382, 2383, 3404, 2906, 3452, 3451, 3453, 3454, 3456, 4767, 4768, 4769, 4770, 724, 719, 721, 723, 722, 464, 6942]

route 214\_1, 62-6

[6942, 621, 620, 622, 624, 625, 623, 4763, 4764, 4765, 4766, 3455, 3457, 3458, 3459, 3460, 3461, 3423, 2310, 2312, 2313, 3462, 3466, 3463, 3464, 3465, 3468, 3289, 3288, 3290, 3467, 3470, 3469, 3472, 3471, 3474, 3473, 3476, 3475, 7209]

route 98\_0, 62-7

[7210, 3436, 3437, 3438, 3439, 3440, 3441, 3442, 3443, 3444, 3311, 3313, 3312, 3446, 3445, 3448, 3447, 3450, 2381, 2382, 2383, 3404, 2906, 3452, 3451, 3454, 4767, 4769, 724, 719, 721, 723, 464, 8]

route 98\_1, 62-7

[8, 621, 620, 622, 624, 625, 623, 626, 4763, 4764, 4765, 4766, 3455, 3457, 3453, 3459, 3460, 3461, 3423, 2310, 2312, 2313, 3449, 3466, 3463, 3464, 3465, 3468, 3289, 3288, 3290, 3467, 3470, 3469, 3472, 3471, 3474, 3473, 3476, 3475, 7210]

route 99\_0, 62-8

[7211, 3427, 3428, 3429, 699, 698, 701, 700, 703, 3431, 3432, 702, 704, 705, 706, 711, 708, 712, 709, 714, 710, 716, 713, 119, 4149, 140, 718, 715, 720, 717, 724, 719, 721, 723, 722, 8]

route 99\_1, 62-8

[8, 621, 620, 622, 624, 623, 626, 627, 628, 629, 1386, 117, 116, 630, 631, 632, 633, 634, 635, 636, 637, 7039, 639, 640, 3422, 3430, 641, 643, 644, 645, 646, 3876, 3424, 3425, 7211]

route 100\_0, 62-9

[7212, 3116, 3119, 3118, 3121, 3120, 3123, 3122, 3125, 3124, 3127, 3126, 3128, 3129, 3131, 3130, 3133, 3132, 3136, 3134, 3137, 3135, 3139, 3138, 2247, 2244, 2246, 2248, 496]

route 100\_1, 62-9

[496, 2148, 2149, 2151, 2150, 2153, 3019, 3020, 3021, 3023, 3025, 3024, 3026, 3027, 3028, 3029, 3030, 3031, 3032, 3033, 3034, 3035, 3036, 3038, 3039, 3040, 3041, 3042, 4421, 7212]

route 107\_0, 70-1

[7509, 790, 783, 784, 792, 794, 785, 796, 787, 788, 963, 732]

route 107\_1, 70-1

[732, 734, 733, 738, 735, 741, 736, 743, 737, 745, 739, 7509]

route 108\_0, 70-2

[7261, 790, 784, 792, 794, 785, 796, 787, 963, 732]

route 108\_1, 70-2

[732, 734, 733, 738, 735, 741, 736, 743, 737, 745, 4680, 739, 7261]

route 109\_0, 70-3

[7218, 790, 792, 785, 963, 7617, 7135, 3654, 1384, 3658, 3660, 1389, 1390, 1395, 1235, 1234, 1393, 1239, 167, 172, 169, 174, 173, 176, 175, 178, 181, 179, 183, 182, 184, 603, 606, 608, 607, 610, 609, 611, 613, 614, 615, 440, 465, 3170, 2405, 164, 35]

route 109\_1, 70-3

[35, 89, 385, 387, 3182, 433, 503, 546, 505, 506, 507, 548, 508, 509, 510, 555, 259, 262, 263, 265, 266, 267, 270, 271, 272, 273, 275, 277, 1115, 1152, 1156, 1155, 1303, 1305, 1304, 3639, 1307, 1306, 1309, 3648, 734, 741, 743, 739, 7218]

**route 110\_0, 70-5**

[7281, 955]

**route 110\_1, 70-5**

[955, 7281]