

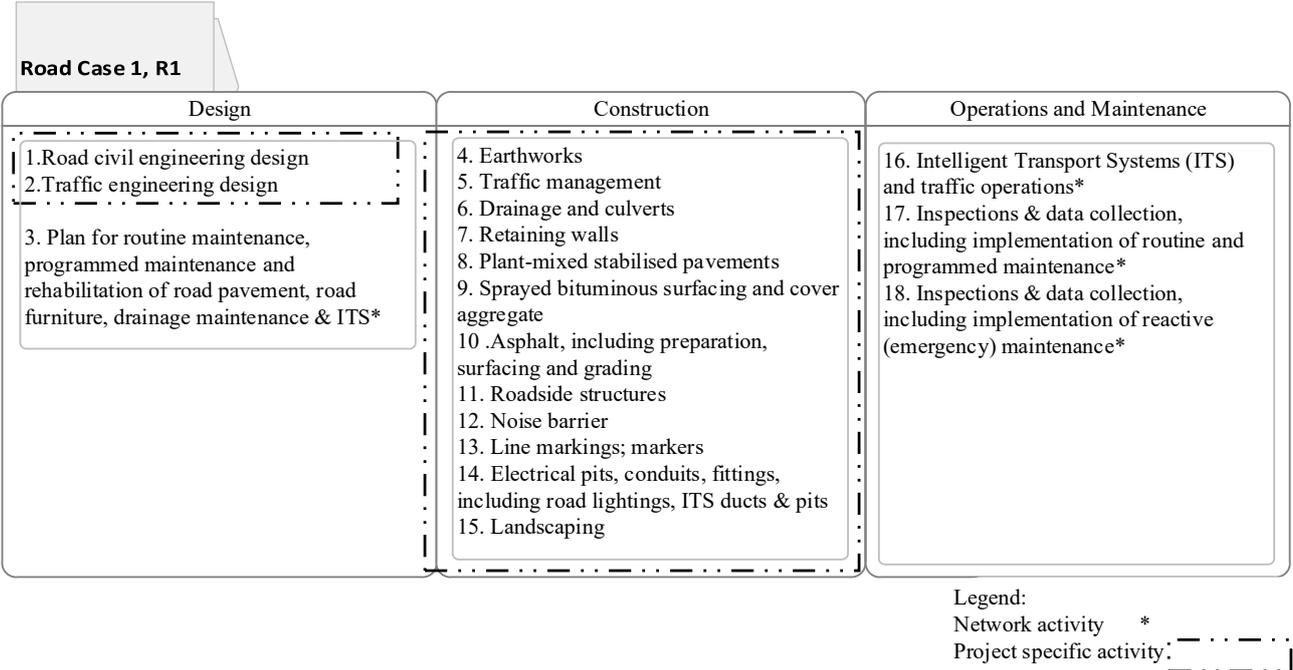
Supplementary Material

The results arising from each procedure in the model are as follows.

Activity analysis and project specific-or-network analysis

Road case 1, R1 is a road widening project of a section of an existing motorway. The activity analysis identified 18 key DCOM activities (Figure S1). The D and C were identified as project-specific activities given its “one-off” requirements, unique timing and geographical location. However, Activity #3 - planning for routine and programmed maintenance and O and M activities (#16 to #18) were considered substantially similar to the recurrent activities in the state government’s network of state and suburban roads. These activities can be procured along with the existing recurrent activities and achieve efficiency gains through economies of scale.

Figure S1. Summary of Activity and network analysis in R1



Road case 2, R2 is a busway project which comprised of on-grade roads, bridges, ramps, a driven tunnel, two cut-and-cover tunnels and two bus stations. 61 DCOM activities were identified (Figure S2). Like R1, the O and M activities (#59 to #61) were network activities. The planning for routine and programmed maintenance to elements in the driven tunnel (#8)

was assessed as project-specific, whereas the planning for maintenance to the rest of the project (#7) was identified as a network activity. The remaining D and C activities to the entire project were considered different and one-off in nature to the recurrent activities in the existing network and were assessed as project-specific activities.

Figure S2. Summary of Activity and network analysis in R2

Road Case 2, R2	
Design	Construction
<p>Design of construction</p> <p>1. Civil & structural engineering design 3. Traffic engineering design 4. Mechanical & electrical engineering design including air quality & ventilation 6. Landscaping & urban finishes design</p>	<p>Cut and cover tunnels</p> <p>9. Relocation of existing public utility plant, 10. Removal works, 11. Traffic management, 12. Bored piles, 13. Excavate and shotcrete, 14. Earthworks, 15. Structural, 16. Precast concrete, 17. Waterproofing, 18. Drainage, 19. Pavement, 20. Modifications to existing bridge and footpath, 21. Demolition, 22. Realignment of rail track</p>
<p>Design of driven tunnel</p> <p>2. Civil & structural engineering design to the driven tunnel, 5. Fire safety design for tunnels, 8. Plan for routine and programmed maintenance to specialist linings, mechanical, electrical & fire elements in driven tunnel</p>	<p>Driven tunnel</p> <p>23. Excavation in tunnel and shotcrete, 24. Waterproofing, 25. Structural, 26. Concrete - barriers, kerbs and wall, 27. Drainage, 28. Trimming & backfill of main tunnel, 29. Pavement, 30. Ventilation fans</p>
<p>Design of performance specification of maintenance</p> <p>7. Plan for routine, programmed maintenance and rehabilitation of road pavement, road furniture, drainage maintenance & ITS*</p>	<p>Bridge, ramps, median, walkway & bikeway</p> <p>40. Traffic management, 41. Earthworks, 42. Pile foundation, 43. Structural works, 44. Precast concrete: barriers, kerbs</p>
<p>Operations and Maintenance</p> <p>60. Inspections & data collection, including implementation of routine & programmed maintenance * 61. Ditto reactive (emergency) maintenance* 59. ITS and traffic operations*</p>	<p>Road at grade</p> <p>31. Bulk excavation, 32. Subgrade preparation, 33. Drainage, 34. Concrete pavement, 35. Precast concrete: barriers, kerbs, 36. Retaining walls, 37. Asphalt pavement, 38. Re-alignment of existing busway, 39. Traffic management</p>
	<p>Remaining construction activities in multiple parts of the project</p> <p>55. Line marking and signage, 56. Landscaping, 57. ITS, 58. M&E (power supply, lighting, and fire services).</p>
	<p>Bus stations</p> <p>45. Water and stormwater, 46. Electrical and communication, 47. Pile foundations, 48. Cast insitu concrete (lift well, platforms, and bus bays), 49. Structural steelwork, 50. Roofing and drainage, 51. Cladding and louvres, 52. Glazing, 53. Mechanical services, 54. Lift installation in bus stations</p>

Legend:
 Network activity *
 Project specific activity

Health case 3, H3 comprised of the delivery of a main hospital building, two buildings for mental health facilities and the upgrade of four existing buildings. The main hospital building is over 35,000m2. A total of 79 activities were identified (Figure S3). In contrast to roads, the efficiency gains in health projects arise within the physical boundaries of the building, particularly in relation to the highly specialized mechanical and electrical services, including the Building Management Control System (BMCS). In this case, all DCOM activities

are dissimilar to the existing network of recurrent activities and are considered as project-specific activities.

Figure S3. Summary of Activity and network analysis in H3

Health Case 3, H3		
Design	Construction	Operations & Maintenance
<p>Detailed performance specification</p> <p>1. Architectural, 2. Structural & civil, 3. Mechanical & Building Management Control System (BMCS), 4. Electrical, 5. Hydraulics (wet fire systems & medical gases and pneumatic tubes), 6. Dry fire systems, 7. Landscape, 8. Helicopter landing</p> <p>Developed design to contract documentation design</p> <p>9. Architectural, 10. Structural and civil, 11. Mechanical, 12. Electrical, 13. Hydraulics (including wet fire system, 14. Dry fire systems, 15. Landscape design 16. Helicopter landing design (developed design to contract documentation design. 17. BMCS, 18. Hydraulics (medical gases and pneumatic tubes)</p> <p>Design of O&M performance specification</p> <p>19. Operations: BMCS; utilities management services; security services 20. Maintenance: Preventive (programmed/non-specialised and specialised)</p>	<p>21. Site establishment, 22. Demolition, 23. Excavation (Bulk and detailed), 24. Concrete. formwork, reinforcement, 25. Prestressed floors 26. Structural steelwork, 27. Masonry, 28. Carpentry, 29. Plasterboard linings, 30. Operable walls, 31. Metalwork, 32. Stainless steel, 33. Joinery and pathology furniture, 34. Roofing and cladding, 35. Doors, 36. External windows, 37. Internal windows, 38. Glazed screens, 39. Hardware, 40. Cement floors, 41. Epoxy floors, 42. Carpet finishes, 43. Ceramic tiling, 44. Vinyl finishes, 45. Plaster walls, 46. Suspended ceilings, 47. Plasterglass ceilings, 48. Polyester powdercoated ceilings, 49. Painting, 50. Signage and way-finding, 51. Curtains and blinds, 52. Non-specialised FFE, 53. Specialised FFE 54. HVAC, 55. Electrical, 56. Security, 57. Communications, 58. Hydraulics - plumbing and drainage, 59. Hydraulics - Medical gases, 60. Fire services, 61. Sterilizing system, 62. Cool rooms, blood fridges; mortuary cabinets, 63. Lifts, 64. Landscaping, 65. Pavements, 66. Covered ways, 67. BMCS, 68. Hydraulics – Medical gases and Pneumatic tubes</p>	<p>69. Building Management Control System (BMCS), 70. Utility management services including maintenance and continuity of supply and monitoring of electricity; gas; fuel oil; water; sewerage; and surface water, stormwater and in-ground water disposal, 71. Security services. 72. Building, engineering services maintenance (BEMS): Reactive (non-critical/routine and critical/emergency - non-specialised) 73. Reactive (non-critical/routine and critical/emergency - specialised) 74. Planned and Preventative including programmed replacement (non-specialised) 75. Planned and Preventative including programmed replacement (specialised) 76. Cleaning, 77. Landscaping & external works, 78. BEMS: Reactive (non-critical/routine and critical/emergency) - highly specialised: BMCS and Pneumatic tubes 79. BEMS: Planned and Preventative including programmed replacement - highly specialised: BMCS and Pneumatic tubes</p>

Legend:
Project specific activity

Health case 4, H4 was an expansion of an existing hospital which was carried out in two stages. Stage 1 comprised of a four-storey building, a two-storey building, and extensions to existing buildings, totalling over 20,000m2 GFA. Stage 2 consisted of refurbishment works within the existing building. Overall, 56 DCOM activities were identified. All activities were identified as project-specific (Figure S4).

Figure S4. Summary of Activity and network analysis in H4

Health Case 4, H4		
Design	Construction	Operations & Maintenance
1. Architectural, 2. Civil and structural 3. Dry fire systems, 4. Mechanical and electrical, including wet fire systems, 5. Highly specialist hydraulics (including medical gases and pneumatic tubes), 6. Kitchen Design, 7. Landscape, 8. Traffic engineering and systems, 9. Planning for building, engineering services maintenance (BEMS) comprising: <ul style="list-style-type: none"> Reactive (non-critical/routine/non-specialist); Reactive (critical/emergency /non-specialist Critical/emergency/specialist); preventive (programmed/non-specialist and programmed/specialist) 	10. Demolition, 11. Site establishment, 12. Excavation, 13. Bored piers, 14. Concrete; Formwork; Reinforcement, 15. Masonry, 16. Structural steel, 17. Carpentry, 18. Metalwork, 19. Roofing, 20. Roof safety system, 21. Glazing, 22. Doors, 23. Vinyl, 24. Carpet, 25. Ceramic floor/wall tiles, 26. Painting, 27. Signage, 28. Commercial kitchen equipment, 29. Cold room, 30. Security system, 31. Landscaping, 32. Carparking, 33. Covered walkways 34. Hydraulics, 35. FFE (non-specialist items), 36. FFE (specialist items), 37. Building Management Control System (BMCS), 38. Pneumatic tubes, 39. Medical gases, 40. HVAC, 41. Electrical, 42. Lifts, 43. Communications 44. Automatic doors, 45. Façade, 46. Fire services	47. Protective services /security 48. Cleaning 49. Landscaping and external works 50. BMCS Building, engineering services maintenance (BEMS): 51. Reactive (non-critical/routine/non-specialist) 52. Reactive (critical/emergency/non-specialist) 53. Preventive (programmed/non-specialist) 54. Reactive (non-critical/routine/specialist), 55. Reactive (critical/emergency/specialist) 56. Preventive (programmed/specialist)

Legend:
 Project specific activity: —

Make-or-buy analysis

The RBT and TCE questions were answered for each project-specific activity, which generated a pattern that was matched with the closest theoretical pattern in the framework. The outcomes of make-or-buy analyses for all case studies are summarized in Table S1.

Road case 1

All the D and C activities had generated low scores across TCE and RBT variables and were matched to Level 6. No Level 5 and 8 activities were identified. The knowledge and skills required in these activities were widely available and there was a plentiful supply of these firms in the market. These activities were also not critical, and there were some tolerances in response time. Therefore, there was a lesser extent of hold-up to the government in terms of quick response. This means that the market is organizationally superior to the government in terms of

providing a less costly and speedier response. This is because of its position in the industry which enables it to aggregate a greater volume of work and generate workflow, while simultaneously increasing efficiencies when carrying out similar activities.

Road case 2

In terms of design to the driven and cut-and-cover tunnels which required specialist knowledge (#2, #5 and #8), the market ability is technically superior to the government. These activities were associated with product/ion heterogeneity that can create pre-contract market failure, with high scores on Rarity and Imitability, and were matched to Level 8 to be filtered-out. As for the remaining design (#1, #3, #4, and #6), the market is organisationally better than the government to aggregate a greater amount of work, increase efficiencies, and make less mistakes in carrying out similar activities, and were assigned Level 6.

The construction of on-grade roads, bridges, ramps, median, walkway, bikeway, and bus stations (#10 to #57), had low scores for TCE and RBT variables and were matched to level 6, except for #9 and #22. The relocation of public utility plant (#9) required expert knowledge of the plant and could only be carried out by the installer. The rail re-alignment (#22) could only be carried out by the particular public railway provider that has the internal capability and competence to realign its tracks and coordinate the scheduling of train times. Both activities had high scores for the RBT variables and were matched to Level 1 (to be internalized), as market firms were unable to match the government's capability and competence of these activities. The tunnel construction activities (#10-21 and #23-29) had high scores for Asset Specificity and Uncertainty and were matched to Level 5. There were significant uncertainties of the geotechnical conditions and required third party permits depending on the path of the eventual tunnelling works. These Level 5 activities were likely to create hold-up and were filtered-out in Hold-up Analysis.

The installation of large ventilation fans in the driven tunnel (#30), lift installation in bus stations (#54), and M and E in all parts of R2 (#58) were relatively straightforward installations and had low scores for “Asset Specificity” and “Uncertainty”. However, they can only be procured from a limited number of specialized suppliers in the market which gave a high score for “Rarity” and were therefore matched to Level 7.

Health case 3

The design of performance specification (#1-8, #19 and #20) involved a highly complex process to liaise and coordinate amongst the various functional groups and stakeholders, which generated high scores for Uncertainty and Asset Specificity, and were matched to Level 5. The government can be held-up by the amount of time required to develop the schematics and detailed performance specifications. These activities were filtered-out in Hold-up Analysis. The design of the helicopter landing facility (#16) was the only activity that had extremely high scores on the RBT variables and was matched to Level 8. The government was unable to match the market (at procurement decision date) in the immensely rare and costly-to-imitate resources and knowledge required. This activity was filtered-out in High Bid Price Analysis.

The D and C of BMCS (#17, #67) and specialized hydraulics (e.g., medical gases and pneumatic tubes) (#18 and #68) required specialist knowledge and proprietary technology that were not easily sourced in the market. These activities were also dominated by RBT variables but to a lesser extent than #16, as there were more firms with the specific knowledge and technology and were matched to Level 7. Similarly, the building engineering maintenance of reactive, planned, preventative replacement of BMCS and specialized hydraulics (#78, #79) were matched to Level 7. The rarity of the knowledge and technology required made their maintenance beyond the capacity of the state department.

The remaining D and C activities (#9-#15 and #21-#66 respectively) had low scores across RBT and TCE variables and were matched to Level 6. This reflects that the market was organisationally better placed than the government to provide a cheaper response because of its competitive advantage in aggregating workloads, greater efficiencies and competence. The remaining O and M activities (#69-#77) required little training and a good supply of firms was available in the market and were matched to Level 6.

Health case 4

The design for architectural, civil, and structural, dry fire system, landscape, and traffic engineering (#1-#3, #7, #8) were matched to Level 6, while the remaining building engineering services and specialized commercial kitchen design (#4-#6) were matched to Level 7. The state government agency had minimal capacity across all design activities, which were beyond their technical capability. There was a corresponding limited supply of firms with the necessary capability and experience for these Level 7 activities which require specialized knowledge of the design requirements of a hospital. For planning of engineering services maintenance (#9), the government had a greater capacity with a high score for Value, but a low score for Frequency as the project was considered not typical. The low frequency mismatches with the positive capacity, and the resultant pattern indicates either a Level 3 or Level 6. Although the state government can benefit from their on-site maintenance staff's knowledge of the building, a contractor can also acquire this knowledge by directly employing these staff and/or by acquiring site records. Moreover, H4 was procured through Managing Contracting, and the Managing Contractor engages the specialist contractors during construction and, thus, has the specific knowledge of all works and the potential supply chain advantage over state government, including the initial transitional phase in maintenance. In addition to these practical reasons, the frequency variable takes theoretical precedence; thus, the model matches

#9 to Level 6 to be externalized.

The construction activities (#10-#35) scored low for the TCE and RBT variables and were matched to Level 6. These activities Figure characteristics which confirm that the market is organisationally better than the government. The market has the competitive advantage of accessing the supply chain, aggregating greater workflow, gaining competence in organising, and making fewer mistakes, in comparison with the government. In contrast, the supply and installation of BMCS, pneumatic tube system and specialist equipment to meet medical standards) (#36-#38) were considered to be significantly beyond the government's technical capability and were matched to Level 8 to be filtered-out. Hydraulics-medical gases, HVAC, electrical, lifts, communications, automatic doors, façade, and fire services (#39-#46), required specialized technical knowledge that cannot be readily sourced, and were matched to Level 7.

Security services, cleaning, landscaping, and external works, BMCS and the implementation of maintenance that were non-specialized in nature (#47-#53) have received conflicting scores of high Value and low Frequency. Similar to #9, the score on Frequency takes precedence, and these activities were matched to Level 6. For M activities that require specialist attention (#54-#56), there were no conflicting scores between Value and Frequency, and the scores matched the activities to Level 7.

Bundling analysis

The focus in bundling analysis is to exclude activities that may be a source of, 1) pre-contract market failure, in which suppliers can exert their power to set high prices arising from activities with thin competition i.e. Level 8 activities, and 2) post-contract market failure, in which suppliers can behave in a negative opportunistic way and hold-up government arising from activities with a high level of unpredictability i.e. Level 5 activities; and 3) subsequently bundle the remaining Level 6 and 7 activities if assessed as not creating a Level 8 bundle of activities.

Road case 1

As there were no Level 5 and 8 activities identified and O and M were assessed as network activities, the model recommended bundling the Level 6 D and C activities into a single bundle which is a more efficient approach than separating D from C. The bundling of these activities did not result in a Level 8 bundle, and therefore one D and C contract of the entire road project.

Road case 2

The civil and structural design of the driven tunnel and fire safety design to tunnels (#2, #5, #8), were identified as Level 8. These activities were reviewed and assessed if it was possible to unbundle each activity to the next tier of suppliers (e.g. Level 6 or 7). However, due to the inherently thin market associated with tunnel design, no Level 6 or 7 could be created. These activities were recommended to be procured as a separate bundle/contract. The construction of cut-and-cover and driven tunnels were identified as Level 5. As these activities were not intimately linked with another activity (no proximity issues were present), and therefore can be procured as a separate bundle/contract. The remaining D and C activities were assessed as Level 6 and 7, and bundling into a single bundle would have resulted in Level 8. The model recommends separating D and C into two separate bundles. In summary, the bundling analysis led to four separate bundles, and therefore four contracts: (1) civil and structural design of driven tunnel, including fire safety design (Level 8), (2) construction of cut-and-cover and driven tunnels (Level 5), (3) design of the remaining part of project (Level 6), and (4) construction of remaining project (Level 6 and 7).

Health case 3

The developed design of helicopter landing (#16) was assessed as Level 8. There was an extreme lack of market supply, and it could not be further unbundled to the next lower tier of

suppliers. The development of detailed performance specification (#1-8) and the design of O and M (#19, #20) were assessed as Level 5. Given no proximity issues exist for these activities, the model recommends procuring these set of design activities as separate bundles/contracts. The remaining DCOM were assessed as Level 6 and 7, and if bundling did not result in a thin market, it can be market sounded for private finance. The analysis led to 3 bundles/contracts: (1) design of helicopter landing (Level 8), (2) detailed performance specification of the project and design of O and M (Level 5), and (3) developed DCOM (Level 6 and 7). Bundle 3 indicates a viable DCOM bundle that can be presented to the market in the following order to gauge the level of interest for private finance.

- (1) One DCOM bundle as a PPP contract; if this does not attract sufficient EoI, then
- (2) One DCOM contract (government funded), if this does not attract sufficient EoI, then
- (3) Four separate D, C, O and M contracts to government for Level 6 and 7 activities.

Health case 4

There were no Level 5, but three Level 8 activities (#36-#38), the supply and install of FFE (specialist items), BMCS, and specialized hydraulics, which could not be further unbundled to the next lower tier of suppliers. As there were proximity issues given the high level of integration required, it will not be practicable to separate these activities from the main construction contract. The model recommended procuring these Level 8 activities, as nominated suppliers in the bundle/contract of Level 6 and 7 DCOM activities. The bundling analysis led to one DCOM bundle of the entire project. Similar to H3, this DCOM bundle can be market sounded as a PPP. If there is insufficient interest, then the market can be tested for a government funded DCOM contract. If this is unable to attract sufficient EoI, then disaggregate the DCOM bundle into four separate bundles of activities/contracts to government.

Table S1. Make-or-Buy Analysis

Level	Case Study 1 (R1)	Case Study 2 (R2)	Case Study 3 (H3)	Case Study 4 (H4)
1		<ul style="list-style-type: none"> Relocation of public utility plant (#9) Realignment of rail track (#22) 		
5		<ul style="list-style-type: none"> Construction - Cut and cover tunnels (#10-21), Driven tunnel (#23-29) 	<ul style="list-style-type: none"> Detailed performance specification (#1-8) Design of operations and maintenance (#19, #20) 	
6	<ul style="list-style-type: none"> Design of construction (#1, #2), Construction (#4-15) 	<ul style="list-style-type: none"> Design – All parts of the project except driven tunnel (#1, #3, #4, #6) Construction – Road at grade (#31-39), Bridge, ramps, median, walkway and bikeway (#40-44), Bus stations (#45-53), construction in multiple parts of the project (#55-57) 	<ul style="list-style-type: none"> Developed design of construction works (#9-15) Construction (#21-66) Operations and Maintenance (#69-77) 	<ul style="list-style-type: none"> Design of construction works (#1-3, #7, #8) Design of performance specification of maintenance (#9) Construction works (#10-35) Operations and Maintenance (#47-53)
7		<ul style="list-style-type: none"> Ventilation fans in the driven tunnel (#30) Lift installation in bus stations (#54) M&E in all parts of the project (#58) 	<ul style="list-style-type: none"> Design of BMCS and specialized hydraulics (medical gases and pneumatic tubes) (#17, #18) Construction works BMCS and specialized hydraulics (#67, #68) Maintenance – Routine and preventive BEMS (#78, #79) 	<ul style="list-style-type: none"> Design of construction works (#4-6) Construction works (#39-46) Maintenance (#54-56)
8		<ul style="list-style-type: none"> Design of Driven tunnel (#2, #5, #8) 	<ul style="list-style-type: none"> Design of helicopter landing (#16) 	<ul style="list-style-type: none"> Construction works (#36-38)