MANAGING SYSTEMS AND TECHNOLOGY IN TRANSPORTATION PROJECTS

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Executive Summary:

With the increasing interest and focus on traffic management measures, often involving the application of high technology and an overall systems approach, it is crucial that our professionals upgrade their skills for this environment.

A survey of 250 large Information Technology projects between 1995 and 2004 shows that only 10% were successful, 20% were moderately delayed or overspent, while fully 70% experienced major delay and overspent or were cancelled. It is most interesting that the root cause for these failures was found to be associated with the project planning and management rather than in the technical solutions and delivery.

From these findings, the Federal Highway Administration (FHWA), USA have identified and recommended application of a system engineering approach for all Intelligent Transportation System (ITS) projects, supported through its issue of associated guidebook publications and an associated series of training courses. The methodology involves applying a full system life cycle approach to the project planning and delivery together with associated feedback processes that are used to verify and validate delivery of the system intentions.

This paper reviews and discusses the application of such techniques for developing and managing the delivery of systems and technology in transportation projects within a New Zealand context. The successful application of these methods and techniques for the Auckland Motorway Corridor Travel Demand Management (TDM) Project within Transit’s “Get Auckland Going” initiative is described. The authors also set out the manner in which such a System Engineering approach is able to be applied in planning and developing integrated transport networks.

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1. Introduction

In the late 1980's, a wide range of Intelligent Transportation Systems (ITS) projects were implemented around the USA with the joint objectives of making transportation facilities more efficient, and encouraging an integrated view of regional transportation networks. The Americans spent a decade learning and improving their process and approach towards planning and implementing systems projects.

A review of Information Technology (IT) systems implementation made by the Federal Highway Administration (FHWA), USA from a study reported by *Jones (1996)* shows that there has been as high as 20% cancellation rate of large software systems and of those completed about 66% are late and/or had overspent.

A subsequent follow-up study by *Jones (2004)* reported that a review of 250 large software projects initiated between 1995 and2004 shows that:

- only 25 projects (10%) were successful in meeting their project objectives
- 50 projects (20%) were delayed or overspent by up to 35% of their expected programme or cost, and
- 175 projects (70%) experienced major delay and overspend, or were cancelled.

The *Jones (2004)* study suggests that the key factors differentiating successful from failing projects are:

- Project Planning
- Cost Estimation
- Project Measurements
- Milestone Tracking
- Change Management, and
- Quality Control.

It is of particular interest to note that all these factors are associated with project management approach rather than technical solutions. It is for this reason that over this present decade there is increasing recognition that new approaches, new skills sets, supported by new capabilities and much improved inter-agency cooperation are all required for the successful delivery of properly integrated ITS.

This paper reviews and discusses the application of such techniques for developing and managing the delivery of systems and technology in transportation projects within a New Zealand context.

A study undertaken by *Siemens ITS., et al. 2005* for the FHWA set out the basis of a recommended systems engineering approach able to address these key project management challenges, resulting in their publication of a "System Engineering Guidebook for ITS". All ITS projects funded by FHWA since then have been required to be based on such a system development process.

As part of Transit's initiative to "Get Auckland Going", Transit New Zealand (Transit) has worked collaboratively with Auckland's regional, city and district councils, and Land Transport NZ to launch the Auckland Motorway Corridor Travel Demand Management (TDM) Project. It was envisaged from the outset that such project would necessarily involve various transportation technological systems and to increase the chance of success, Transit has adopted the FHWA-recommended system engineering approach to its delivery of the overall project.

2. System Engineering Approach

The approach adopted by the FHWA for delivery of ITS projects as recommended by *Siemens ITS., et al. 2005*, uses a "Vee Development Model". This Vee Development Model is developed by combining and adapting other existing proven system development process tools such as the Waterfall and Spiral Models used by other industries such as within information technology and defence, where similar technologies are used.

An illustration of the Vee Development Model and its application to the project lifecycle is shown in Figure 1. The following sections of this paper describe what is involved in each individual phase.

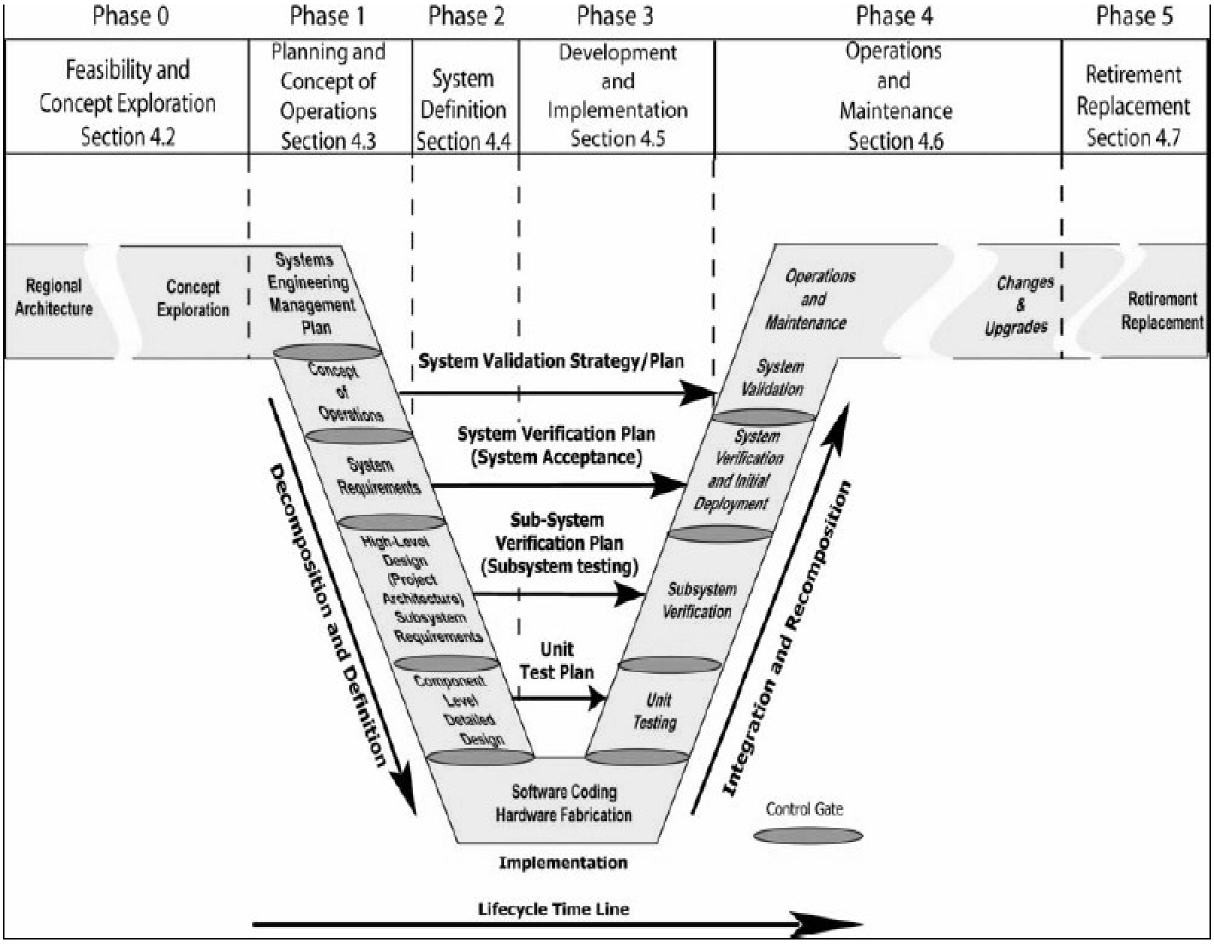

Figure 1: Vee Project Development Lifecycle Model

This development model is a good guideline for the processes to be used when implementing ITS projects. Figure 2 extracted from *Siemens ITS., et al. 2005* similarly illustrates the optimal level of formal systems engineering process required for a project.

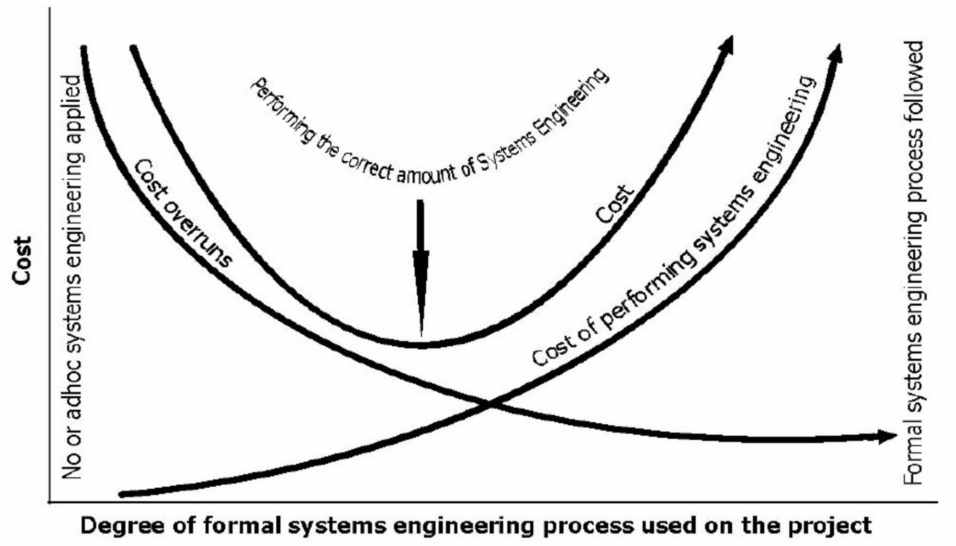

Figure 2: Optimal level of formal systems engineering process required for a project

As is shown, the amount of system engineering needed for a project depends on the following matters:

- Project risks
- System complexity
- Number of stakeholders
- Number of interfaces
- Decisions that need to be made
- Existing documentation

Within particular projects, and interpreting these factors with appropriate engineering judgement, experience and institutional understanding, the Project Manager should be able to tailor the level of effort required for system engineering process.

As a general rule of thumb, *Siemens ITS., et al. 2005* suggests some estimates of the percentage level of effort required within each corresponding phase of a project.

Planning	Definition	Design	Implementation	Integration/Verification
10%	15%	20%	30%	25%

Table 1: Proportional Effort in Systems Engineering

Internationally, and as noted earlier, a significant proportion of IT and ITS programmes started with the best of intentions but have failed to deliver up to stakeholders/users expectations.

Applying the Vee Model, the project delivery is undertaken with both a “Top Down” and “Bottom Up” approach. Here, “Top Down” refers to planning and designing the system from high level to detailed level. Similarly, “Bottom Up” refers to the verification process undertaken by the System Engineers (Consultant/Contractor) responsible for the project planning and delivery to determine whether the system “*is built correctly*”, and validation by the relevant Stakeholders that “*the correct system has been built*”.

Figure 3 extracted from *Siemens ITS., et al. 2005* illustrates the cycle that such system engineering involves. It can be seen that the system development does not just stop when construction/installation is completed. All of the steps of system monitoring, intervention, learning and development are being continually pursued to encourage ongoing improvement.

Figure 3: Continuous Improvement Cycle

It must be emphasised that stakeholder involvement is regarded as one of the critical success factors for a system project. Early stakeholder involvement ensures that the needs, problems, issues, and constraints are examined, prioritised and addressed during all of the full project lifecycle. Such involvement during the early project planning stages is very important in ensuring the successful and accurate definition of the series of project goals and objectives that are the key to validating the completed and delivered system.

Stakeholder workshops at appropriate hold points provide a valuable means of involving stakeholders in this process. While it is unusual that all stakeholders will be able to fully agree on all issues, such occasions provide the opportunity to discuss and understand the issues and constraints, and in turn enable conscious project planning and design decisions that are well thought out, well discussed and well reviewed. To be effective, it is very important that the opinions and suggestions from each stakeholder are encouraged, fully discussed and given respectful consideration. In the New Zealand setting, such of transportation system stakeholders would normally be expected to include but not be limited to:

- Internal Stakeholder:
  - Owners
  - Operators
  - Users
  - Developers
  - Maintenance and management.

- External Stakeholder:
  - Regional, City and District Councils
  - Transportation authorities
  - Transit New Zealand
  - Land Transport NZ
  - Emergency Services e.g. Police, Fire, Ambulance
  - Transport services agencies e.g Freight, Buses, Taxis

3. Concept of Operations (System Planning)

The TDM project started off its system planning by first defining the overall system stakeholders (Who), and in turn then drawing out their individual needs and requirements (What). This was undertaken by one-to-one meetings with each individual stakeholder. The care and detail with which this first step is taken is usually found to be crucial to the overall eventual success of the project.

These processes in turn then enable stakeholders to work together in developing the overall Project Vision as a concise statement of the outcomes the project is to deliver. Such discussions and workshops involving all stakeholders would then be expected to establish:

- the overall Project Vision Statement
- the particular Project Goals
- the specific Project Objectives
- the series of Actions needed to achieve the project objectives, and
- a schedule of the Performance Indicators that will be used to measure the project success.

In Transit's TDM ramp signalling project, the outcomes under each of these headings has beenused to form the basis of the Project Partnering Charter within which all of the participant formalises their commitment to work together in an open and honest manner to achieve the mutually agreed goals. A copy of the TDM Project Partnering Charter extracted from *Beca., et al. 2005* can be found in the Appendix of this report.

Following this, preparation of the Concept of Operations report has then been undertaken to document the manner in which the completed TDM system is to operate, and how the system will meet the needs and expectations of the different stakeholders. At this stage and importantly, the primary focus is on the user's operational needs, and not the detail of the system design.

A full gap analysis between the TDM project goals and objectives against the current Transit operational system was undertaken. *Beca., et al. 2005* reported that through this gap analysis, a more active traffic management system, including flow monitoring and surveillance, lane management (priority lanes) and ramp signalling together with an associated comprehensive Traveller Information Service (TIS) is required.

Various combination of traffic management tools e.g. ramp signalling with TIS, ramp signalling without TIS were considered as alternative operational concepts and assessed against the TDM project goals and objectives and Land Transport Management Act criteria (for funding purposes). *Beca., et al. 2005* reported that the ramp signalling with TIS achieves significantly more of the established goals and objectives than other considered combination of traffic management tools, and hence has been included as a key part of the preferred concept of operations.

In order to convey the concept of operations in a non-technical and easy to understand manner, the TDM project makes use of easy and short scenarios from the viewpoints of various stakeholders to illustrate their experience in using the proposed concept. *Siemens ITS., et al. 2005* shows such use of flowcharts, thread tracking, and flow analysis as important techniques in these projects.

Siemens ITS., et al. 2005 suggested that at this stage of the project development, the system planning should desirably have established:

- the particular role and responsibilities of each stakeholder
- the intended operational system characteristics
- the proposed operational philosophy, and
- the overall system expectations including particular constraints and limitations.

4. System Definition and Design

Siemens ITS., et al. 2005 showed that within the Vee Model, the next steps in the system definition and design phase can be broken down to three levels:

- System Level Requirements (System Definition)
- High Level Requirements (High-level Design)
- Component Level Requirements (Detailed Design)

The system level requirement is used to define "WHAT the system is to do" which is derived from the Concept of Operations. Within the TDM project, this level involves identifying all of the expected functions, performance parameters and environmental conditions for the system delivery. The outcome of this process is a set of defined functional requirements for:

- Ramp Signalling
- ATMS Interface
- Travel Information Services
- Performance Metric
- SCATS Interface
- Traffic Management Centre Operators
- Supervisory System

It is important to develop "good" system level requirements, as much of the preparation of the design flows from them. On the other hand, if this definition of the system level requirements is incorrect and inaccurate, it is almost certain that the subsequent design of the system will be incorrect and will need to be repeated. Proper undertaking of this task will minimise the risk of re-work. It can be noted under this heading that the cost impacts of making changes at the early development stage are low whereas the cost of making the same change later are very much higher. The author suggest that generally, $1 worth of changes during the project planning phase corresponds to a $10 cost of making such a change during the project design phase, and $100 if made during the project construction/installation phase.

Siemens ITS., et al. 2005 suggested the following list of attributes as a guide for determining what should be regarded as "good requirements". These should be:

- **Clear** - easily understood, unambiguous
- **Complete** - contains everything pertinent
- **Consistent** - free of conflicts with other requirements
- **Correct** - specifies what is actually required
- **Feasible** - technologically possible
- **Objective** - no room for subjective interpretation
- **Need Oriented** - state problem only, no solutions
- **Singular** - focus on only one subject
- **Succinct** - free of superfluous material, avoid over specification
- **Verifiable** - can be measured to show need is satisfied

The system definition phase finishes off with its development of a corresponding system verification plan setting out the tests that will demonstrate the system is developed correctly.

The High Level Design phase which then follows is the transitional step between "What" the system does (System Definition), and "How" the system will be implemented (Detailed Design). It describes the project level system architecture which defines the required system element/sub-systems themselves, and the connections and interface between each of the system element/sub systems (can be hardware, software, database and people). This step also describes the integration and verification activities needed when the system elements are developed.

The Ramp Signalling project level system architecture extracted from *Transfield (2006)* can be found in the appendix section of this paper. This is developed by breaking down the system requirements and developing alternative project architectures that meet the system requirements. These alternative project architectures are then evaluated using particular pre-determined criteria such as performance, functionality, cost, maintenance, lead-in time/development time and complexity. It should be noted that for the Ramp Signalling project, the initial step in this process has been undertaken during the tendering stage where the different proposed project architectures by contractors have been considered and evaluated by Transit.

The key output from the High Level Design is the project level system architecture, sub-system requirements and verification plans, and the sub-system integration plans.

The component level requirement is the final stage of the system design. This task will define "How the system will be built" and the system component specifications.

For the ramp signalling project, off-the-shelf (OTS) products have been selected for the system elements/components, hence defining the component level requirements as straightforward since the component manufacturers are able to provide specifications for each of the supplied system elements. It should be noted that when evaluating the suitability of any OTS element, care should be taken to identify and assess the nature and effect of any gaps between the system requirements and the OTS product specifications. Where gaps are identified, the stakeholders should decide whether if a deviation from the system requirements is appropriate.

Siemens ITS., et al. 2005 suggest that where new development is required for a system element, detailed design is needed to provide specifications for a product to meet the component level requirements. This needs to be sufficiently detailed and clear such that manufacturing and/or coding of the product is possible.

During appropriate hold points within the system definition and design phases, system walkthroughs are very beneficial. *Siemens ITS., et al. 2005* defined a system walkthrough as a review process where stakeholders meet to verify the requirements in order to ensure that there is a common understanding of their intent. This is suggested both at the initial development of the requirements, and again when any of the particular requirements are modified or changed. It is also very important to ensure traceability of the system requirements as they are developed, as this greatly assists the system walkthrough process and checking. Traceability shows how the requirements relate to each other at different levels, and how the system requirements relate back to the Concept of Operations.

5. System Implementation

With the system design completed, the order and purchase of any OTS product, and/or new product manufacturing may commence. For the Ramp Signalling project, various elements such as CCTV, Ethernet switches, traffic signal lantern, controller and detectors has been progressively made available and progressively integrated and inter-connected to fully develop the overall Ramp Signalling Project System. It is only after the overall Project System is fully developed and tested that it can be integrated with any existing System such as SCATS.

This phase involved integration of the project sub-systems and system elements which are complex and requires active monitoring and co-ordination. It is recommended that Configuration Management also be applied as a further method that can materially assist with this phase especially where changes may occur during the system implementation and integration phase.

Siemens ITS., et al. 2005 define Configuration Management as a process where information regarding the functional and physical characteristics of the overall systems and individual system/sub-systems elements from reports developed during the system definition and design phase are extracted and compiled. This information is used to track and manage each of the design changes needed in ensuring that any changes have not jeopardised any of the original system intents and requirements.

The Ramp Signalling project also makes use of a Configuration Management Board that meets on a weekly basis to undertake this management task and make decisions on any changes required. This Board consists of Transit's Project Manager, Ramp Signalling Operations Engineer, Contractor's Systems Project Manager and the contract Engineer's Representative.

6. System Testing

Siemens ITS., et al. 2005 suggested through the Vee Model that the next step of system testing can be divided into four levels:

- Unit Testing – Detailed testing and verification of each individual system/sub-system element.
- Sub-System Testing – Testing and verification to ensure sub-system elements can be integrated and made properly operational.
- System Testing – Testing and verification to ensure the overall system elements can be integrated and made operational.
- System Validation – Testing and validating to ensure the right product has been built.

For the Ramp Signalling project, the unit testing, sub-system testing and system testing were undertaken through a series of Factory Acceptance Test (FAT) and again during the Site Acceptance Test (SAT). The system validation test will be undertaken by the stakeholders as a final System Acceptance Test

Each of these testing procedures should be undertaken according to the test/verification and validation plans developed during the system definition and design phase. *Siemens ITS., et al. 2005* recommended the use of a Traceability Matrix of the form shown in Table 2 to ensure that the system test plan developed is suitably consistent and meets all of the system requirements.

Requirements No.	Specifications No.	Implementations No.	Tests No.
1.1	1.1	2.0	1.0
1.2	1.2	6.8	4.0
2.1	3.83	17.6.1, 15.2, 18.2.1	8.0
2.2	4.9	12.2, 18.2	2.0
2.3	5.1	6.3	9.0

Table 2: Example Traceability Matrix

The above traceability matrix shows test number 1.0 is for testing implementation number 2.0 which is related to specification number 1.1 that is used to achieve requirement no 1.1. This matrix will only be suitable if the requirements, specification, implementation and tests are carefully and clearly numbered from the outset of the project.

7. System Operations and Maintenance

When the system has gone through all the acceptance tests, it will enter the Operations and Maintenance phase (O&M). This is the real and final test of how useful and successful the system is; the right system might be built correctly but if it is not being used as intended due to a lack of operating resources or funding for maintenance for example, then the successfully developed system is not successful.

To avoid such an outcome, *Siemens ITS., et al. 2005* suggested that O&M must be recognised as a key consideration and influencing factor during all of the system planning and design stages. During early stages of this phase, O&M documents and ideas developed from the system planning and design stage are usually complied and finalised to develop a System Owner’s Manual.

As a minimum, the system owner’s manual for the Ramp Signalling project would describe and detail the following:

- the on-going O&M funding requirements, generally for every $1 spent on development, $2 is spent on maintenance
- the components of the system needing O&M. A system component inventory list is a good way to undertake this task
- the as-built drawings
- a maintenance manual which includes the configuration record, and the procedures that are to be used in O&M
- descriptions for the personnel who will be responsible for O&M. This may include description of the skill level requirements (job descriptions).
- training procedures and plans for operational staff (initial and ongoing)
- key performance measures for the required O&M including what and where data is available, and how it is processed and reported.

As O&M progress, monitoring and learning is also important to continually enhance the system. Over time, it is expected that system requirements and process may be refined and updated due to changes in environment and conditions and/or the operational learning experience gained. Accordingly, and repeating the same pattern, this phase is itself also the very beginning on the next evolutionary Vee system lifecycle development, as is shown in Figure 4 extracted from *Siemens ITS., et al. 2005*.

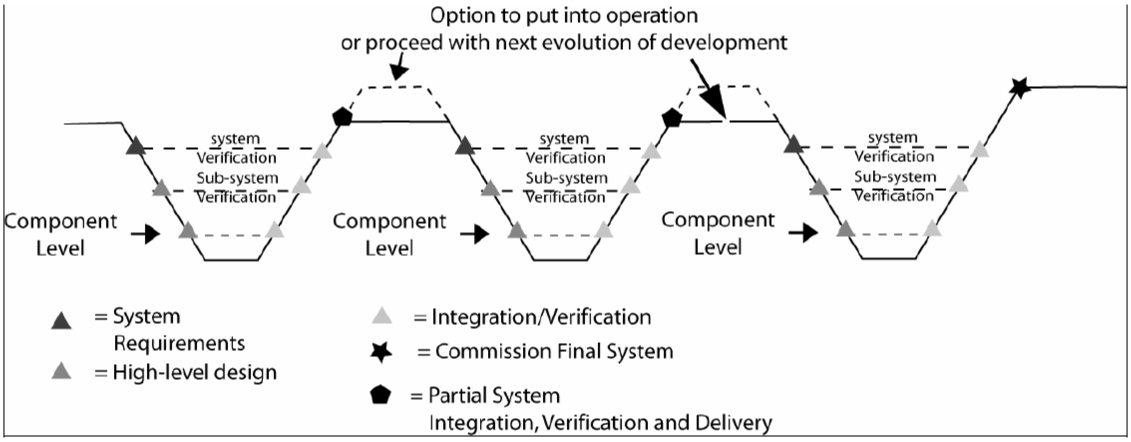

Figure 4: Evolutionary Vee system Lifecycle Development Model

This evolutionary form of the Vee diagram repeats the same underlying processes of definition, high level requirements, detailed requirements construction, commissioning and verification used in the project model described set out earlier in this paper.

8. Vee Lifecycle Approach to Developing Integrated Transportation System

It may be possible to suitable adapt and apply the Vee lifecycle model into the task of developing a integrated transport systems in urban areas.

The top down approach for planning, defining and designing such an Integrated Transportation System can be undertaken as below:

- **Concept of Operations Phase**: To commence the process, the project vision, goals, objectives and performance indicator for the Integrated Transportation System will be first need to be developed. With these suitably established, the operational characteristics and philosophy can then in turn be developed. This may involve definition of such matters as the target modal split percentages for different trip lengths and purposes etc.

- **Defining and Designing the System**: Questions regarding <u>what</u> the integrated transportation system does, and <u>how</u> it can be put together need to be fully addressed. These steps can in turn then be broken down to determine the various functional requirement levels similar to those discussed in Section 4 of this paper.

It should be noted that although different sub-systems e.g. train services, bus services, roading networks, may have different ownership, they will likely have the same goals i.e. moving goods and people. The key to success in designing properly integrated transportation networks will invariably lie in ensuring proper stakeholder involvement from the outset.

Similarly, the bottom up approach for verifying and validating the intended system can test by checking that each component sub-system is operating to its particularly defined sub-system requirements, that the integrated system is similarly operating to its requirements, and finally validating that the overall Integrated Transportation System is performing in its delivery of the desired vision, goals, objectives and performance indicators. It should be noted that the Planning ⇒ Executing ⇒ Monitoring ⇒ Intervention ⇒ Learning ⇒ Planning cycle and/or the evolutionary Vee Model is well suited to situations where continuous improvement is expected.

9. Conclusions

To increase the success of ITS implementation projects, it is crucial that our professionals upgrade their project management skills for this different environment.

The System Engineering Guideline published by the USA Federal Highway Administration (FHWA) describes and recommends a Vee System Development Lifecycle Model for ITS project development. Transit New Zealand has adapted and applied this Vee model for a range of major and complex Travel Demand Management systems projects including their top priority Ramp Signalling project in Auckland.

This innovation application of the state-of-practice to the Ramp Signalling project described within this paper has proven to be very useful. The process as set out in this guide has enabled objective and goals of the project to be carefully and clearly defined, and mutually agreed by project stakeholder from the project outset.

Using the Vee System Development Lifecycle Model, the Ramp Signalling project is able to plan and define a project beginning from its high level requirements, and extending progressively through to development of its corresponding detailed requirements. This would then be used to finally verify and validate the implemented Ramp Signalling System to confirm its desired outcomes are properly achieved.

The System Engineering Guideline recommends that Stakeholder Involvement, System Walkthrough, Configuration Management, and Traceability be regarded as the key tasks to assist with this process.

The authors consider that the application of such Vee Model systems engineering techniques will similarly be found valuable in developing an integrated transport solution for urban areas. The methodology includes an Evolutionary Version of the same Vee Model approach that is well suited for such projects directed at enabling progressive improvement of outcomes.

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APPENDIX:

Auckland Motorway Corridor
Travel Demand Management Project
Partnering Charter

The participants vision is to actively influence travel patterns and manage corridor traffic conditions, using flow monitoring and control systems together with delivery of traveller information, to optimise the operation of the motorway and its supporting arterials

To achieve this vision, the participants seek to foster an environment conducive to working together in an open and honest manner to deliver the following goals:

1. Achieve change in travel behaviour through travel demand management
2. Improve the motorway system interface with the local arterial network
3. Support the traffic demand management objectives of the Regional Growth Strategy, Regional Land Transport Strategy and Long Term Council Community Plans
4. Deliver reliable travel times within the motorway corridor
5. Actively manage the corridor so as to improve overall efficiency of travel
6. Improve operating safety
7. Improve the travel efficiency for priority vehicles such as public transport and freight
8. Ensure transport system users and operators are well informed
9. Manage the traffic effects of incidents
10. Develop a project that the public can understand
11. Undertake on-going monitoring of and responses to the project impacts
12. Establish and maintain commitments towards continuous improvement of project outcomes

Figure 5: Auckland Motorway Corridor TDM Project Partnering Charter

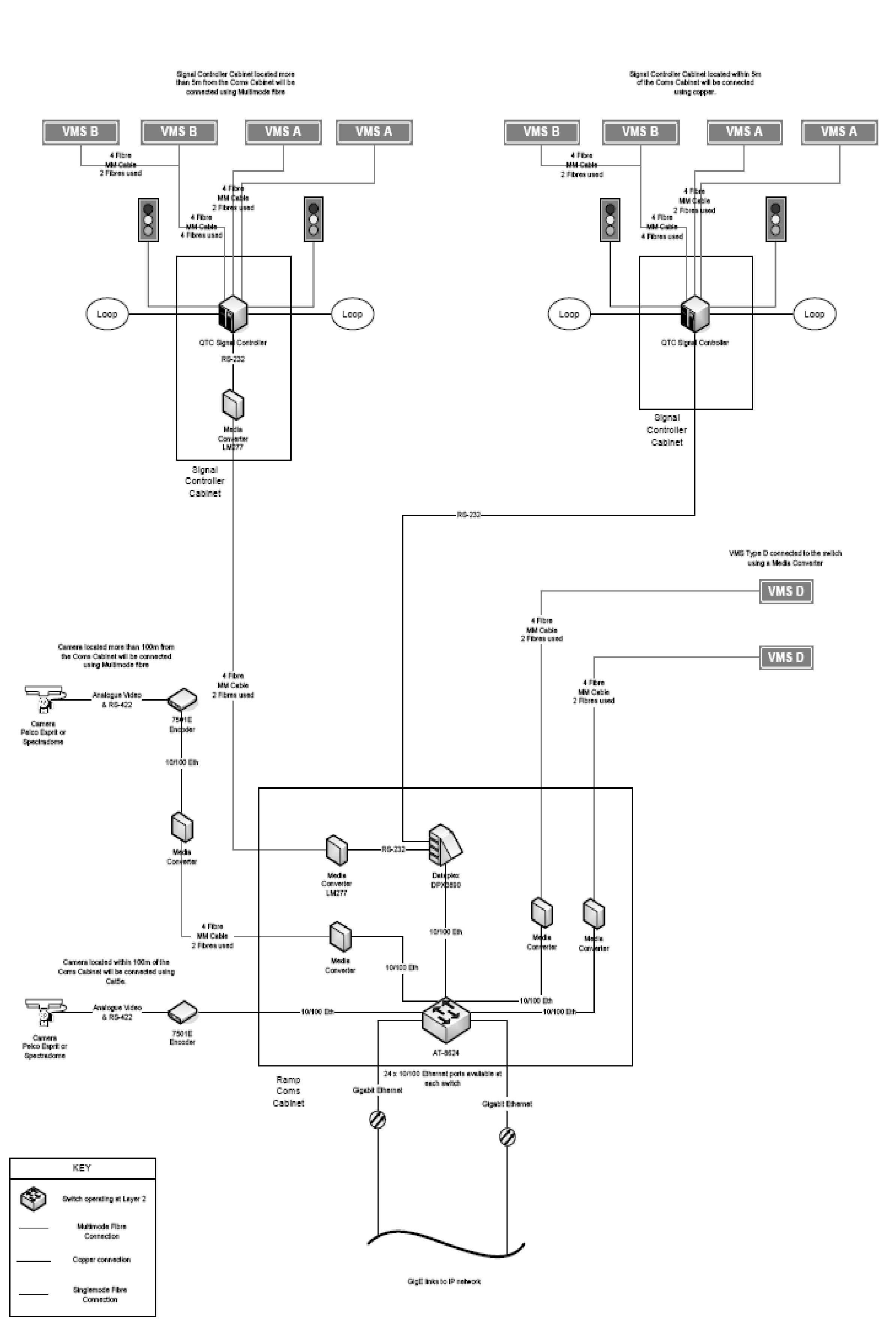

Figure 6: Ramp Signalling Project Level System Architecture