High Value Bridges for Low Volume Road

Julien Henley, Associated Engineering
Ed Cienciala, British Columbia Ministry of Transportation and Infrastructure

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Abstract

Faced with responsibility for a significant number of aging bridges on low volume roads in a challenging economic climate, the Northern Region of the British Columbia Ministry of Transportation and Infrastructure (BCMoTI) is experimenting with alternative methods to procure high value bridges. Realizing that its traditional delivery method for highway bridges was not well suited to small crossings in remote locations, the Ministry adapted the procurement procedures widely used for bridges on industrial roads.

In addition to adopting a modified version of design standards that have been in place with the British Columbia Ministry of Forests and Range, they have also experimented with alternative procurement methods to facilitate the economical delivery of Low Volume Road Bridges.

The alternative design and procurement methods attempt to maximize the opportunities available to the BCMOTI by using proven alternative design standards, readily available prefabricated components, drawing upon a well-established competitive precast concrete and steel fabrication industry and creating opportunities for smaller lower costs bridge contractors who may not typically bid BCMoTI projects.

Because of these changes, the BCMoTI has economically delivered a large number of replacement crossing in an environment of shrinking budgets. The paper describes some of the changes and provides examples of some of the recently completed successful projects.

1.0 Introduction

Faced with responsibility for a significant number of aging bridges on low volume roads (LVR) in a challenging economic climate, the British Columbia Ministry of Transportation and Infrastructure (BCMoTI) developed a new delivery method to procure high value bridges on roads with reduced traffic.

Realizing that its traditional delivery method for highway bridges was not well suited to low volume crossings located off the traditional paved highway network, the BCMoTI adapted a modified form of the procurement widely used for bridges on industrial roads. By revisiting the design and procurement procedures, the Ministry has been able to recognize significant financial savings. This has resulted in the replacement of more bridges during a time where financial constraints have governments reducing funding for all but the most critical projects.

The BCMoTI based the design and procurement strategies on a modified version of standards developed by the British Columbia Ministry of Forest and Range (BCMoFR) for use on industrial roads. These original standards have served as the basis for the design of thousands of single lane bridges over the last 25 years.

The BCMoTI alternate delivery methods represent a variation on traditional design-build models and partnerships. In the traditional methods used by BCMoTI, each structure is treated as a permanent, independent entity, unique to its location, materials used, configuration, and method of installation. In effect, the traditional model optimizes each structure independently for its specific location, an approach valid for large, complex, main and secondary highway structures. The alternate approach uses standardized conceptual configurations of the various available structures, and then addresses the local requirements and constraints. The BCMoTI also considers the operational design and the fact that these types of structures are generally re-usable in other LVR locations, for example when accessing a small community, is it reasonable to always provide a two lane structure on the possibility that one day the community may be large when a single lane structure will provide a safe economical crossing for 20 years?

Bridge designs typically comprise twin steel I-Girders and full-depth precast concrete deck panels or shear connected precast concrete beams founded on spread footings or driven steel pipe piles. Designers detail all elements to facilitate purchasing of the elements as a separate contract and easy erection using medium sized excavators to minimize mobilization costs. By adopting conservative geotechnical design criteria bridge construction can often proceed with limited geotechnical information.

Further, by adopting an appropriately modified version of existing bridge design standards in use in British Columbia, the BCMoTI is able to draw upon an established and competitive steel fabrication and precast concrete fabrication industry and numerous qualified bridge contractors to ensure competitive tendering.

2.0 What is a Low Volume Road Bridge?

With adoption of alternative design standards and procurement methodologies, the BCMoTI has chosen to define a LVR as one where traffic volumes are less than 500 vehicles per day. The percentage of low volume road (LVR) structures under BCMoTI jurisdiction in the province is approximately 40%, and in the Northern Region these structures represent about 70% of the inventory. Some of these LVR structures are located on numbered highways with traffic counts far below the TAC ADT threshold of 500 vehicles per day. Given the age of this segment and proportion of the total inventory combined with budgetary constraints, significant risk pressures are placed on the BCMoTI.

3.0 The Canadian Highway bridge Design Code and Low Volume Road Bridges

The Canadian Highway Bridge Design Code (S6-06) does not address the unique issues and components typically encountered when designing LVR Bridges. However, it is common to use appropriate modifications to adapt S6-06 for the design of these bridges. Some of these modifications include:

- Removal of the requirement that all new bridges be designed as Class A Highway Bridges.
- Accept that single load path structures are usual occurrences for LVR Bridges.
- Use open curbs to facilitate transverse deck drainage where allowed by regulatory agencies allowing the bridge to be placed on a reduced longitudinal grade.
- Develop appropriate bridge barrier requirements.
- Revise seismic design requirements for LVR Bridges to requiring collapse prevention only.
- Develop appropriate geotechnical design criteria given that geotechnical information may be limited or absent. This also includes structuring contracts to account for this uncertainty without transferring undue risk to the contractor.
- For the design and fabrication of concrete components:
    - Adopt revised cover requirements for precast concrete components given the typical non-corrosive environment.
    - Remove the requirements for corrosion-protected reinforcement.
    - Purpose design all precast concrete deck components to avoid the restrictive requirements mandated for the design of precast decks using the empirical method.
    - Remove the allowance for wear requirement for concrete decks.
- For the design and fabrication of steel components:
    - Remove the requirement for painting steel components adjacent to joints
    - Allow the use of 9.5 mm (3/8”) thick steel plate
    - Revise coating requirements for structures
    - Revise “Number of Design Cycles” for fatigue design criteria to reflect the limited traffic volumes.
    - Allow grouping of shear studs in pockets at spacings greater than 600 mm.
    - Allow per heat testing for steel plate incorporated into fracture critical girders.
    - Allow UT testing instead of X-Ray testing for full and partial penetration welds.

The majority of the recommended modifications address the design of LVR bridges in non-corrosive environments and recognizes the performance of the high quality precast concrete deck components. Notwithstanding this, where bridges are located in more corrosive environments owners should adopt appropriate durability requirements. These could include the use of additional concrete cover, corrosion-protected reinforcement, or painted weathering steel.

4.0 Evolution of the Low Volume Road Bridge

Over the last twenty-five years, the BCMoFR and the British Columbia Forest Industry has successfully installed thousands of single lane bridges ranging in span from 6 m to 96 m. Bridge widths have typically ranged from 4.2 m through 6.0 m. In some instances, wider decks are dictated by geometric constraints, and some two-pane versions of LVR bridges are used where dictated by safety considerations. The designs have evolved from twin steel I-girders with timber decks to twin-steel I-girders with full depth composite precast concrete decks and welded shear connected concrete girder bridges. Typical components now include:

- Precast concrete footings with steel pipe columns.
- Driven steel piles extended to cap level (in soft ground sites, or for intermediate piers)
- Field welding of substructure and bridge bearing components.
- Twin steel I-girders, braced together, with shear connectors grouped in pockets.
- Full-depth precast concrete deck panels with pockets for shear connectors.
- Field grouted deck panel joints and pockets.

- Precast concrete ballast walls.
- PL-1 crash tested bridge rails.
- Welded or grouted shear connected reinforced concrete beams.

Routine inspections of bridges over 15 years old indicate that the majority of components are performing as intended with limited maintenance requirements. The exception is the timber components that require replacement every 10 to 15 years.

The following briefly describes specific components and bridge types.

4.1 Substructure

Due to the location of these bridges or the costs associated with the completion of a geotechnical investigation, it is often not economical to conduct geotechnical investigations and designers infer geotechnical information based on the initial site visit and local knowledge. The first indication of what lies below the surface is typically when the excavation for footings or pile driving begins. To account for this unknown variable a number of solutions are considered.

The preferred solution is precast concrete footings varying in size from 1800 mm to 3000 mm square founded on a gravel-leveling surface (Figure 1). For simplicity, the allowable bearing pressure is limited to 200 kPa. This low allowable pressure accounts for the limited information and is a typical lower bound for granular soils encountered throughout British Columbia. Small settlements using this bearing pressure are acceptable on simply supported spans and approach roads are gravel surfaced allowing for regrading during routine road maintenance. Where Contractors encounter poor soil conditions, they have successfully employed log rafts or rock fill enclosed in geotextile fabric (Figure 2) to reduce the applied bearing pressure and minimize settlements.

Steel pipe columns are bolted onto the footings and bracing field welded in place as required. Given the light weight of the footings (typically less than 10 000 kg), they are easy to place accurately in the field. Bridge bearings are placed directly onto the columns, eliminating the need for a concrete cap. Where a cap is necessary, the design incorporates a precast concrete cap with embedded plates on the underside to facilitate field welding to the steel pipe. Blockouts may be left in the cap so that the bearing anchor bolts can be accurately located and grouted in a later stage.

As an alternative, if rock is encountered and it is deemed suitable for direct bearing, small cast-in-place concrete rock pads can be readily installed on site. Given the limited quantities, contractors often use bagged grout containing course aggregate.

Figure 1
Installation of precast concrete footing

Figure 2
Rock fill enclosed in geotextile fabric

If the initial site viewing suggests that precast concrete footings or cast-in-place concrete rock pads are not suitable, steel pipe piles are considered. Typical pipe piles range in size from 323 mm (12") to 610 mm (24") diameter and are easily driven using a small crane and drop hammer. Piles are often driven to practical refusal or to criteria developed using readily available pile driving formula. As noted previously, the system has the ability to tolerate small settlements. However, for small structures precast concrete footings remain the most economical solutions given the costs associated with mobilizing a crane.

In addition, the inherent flexibility of the substructure results in the use of thin fixed plain elastomeric bearings as designs need not account for thermal strains and large restraining forces associated with stiff abutment structures.

3.2 Earth Retention

Given the typical shorter spans and to expedite construction the bridge length is typically increased to minimize fill retention at the abutment. This results in the ability to use precast concrete ballast walls instead of large cast-in-place concrete bridge abutments or other earth retention systems. The precast ballast walls are connected to the girders using embedded plates in the ballast wall and field welding them to end plates on the girders (Figure 3). Where side slopes have to be retained, concrete lock blocks are often used. Notwithstanding this, the installation of mechanically stabilized earth solutions such as wire-faced walls are becoming more economical where suitable backfill material is available.

An additional advantage of adopting longer structures is that the construction is often moved outside the wetted perimeter allowing installation to proceed outside the fisheries window. This allows contractors to better schedule the bridge installation often resulting in reduced construction and overall project costs.

4.3 Superstructure

4.3.1 Twin Steel Girders and Precast Concrete Decks

This system consists of twin steel girders onto which full width precast concrete panels are placed (Figure 3). Typical construction allows the panels to be grouted to the girders by using discrete grouping of studs and associated blockouts in the precast panels (Figure 4). Once grouted, the system behaves as a composite steel girder.

Figure 3
Typical Twin-Steel I-Girder and Precast Concrete Ballast Wall

For shorter simple span bridges, the transverse joint consists of a 25 mm wide grouted joints. Both deck edges are roughened to ensure a good bond. This joint has proven to be very robust on the narrower 4.2 to 4.8 m wide bridges. On wider bridges where the deck may be subject to both transverse and longitudinal bending a 200 mm reinforced grouted joint is detailed.

Further, to optimize material usage, designs incorporate standard length plate using 3.048 m (10') increments ranging from 6.096 m (20') through 18.288 m (60'). Bridges over 21.336 m (70') typically incorporate bolted field splices to accommodate transportation restrictions. In a similar manner, the precast concrete deck panels are detailed in 3.048 m (10') increments.

Typical span ranges for this system are 9.0-45.0 m. Longer spans are possible with the current maximum single span being 96 m.

Figure 4
Typical Precast Concrete Deck Panel

4.3.2 Precast Concrete Beams

For shorter spans (9.0 m through 15.0 m), solid precast reinforced concrete beams are used in a similar manner to that of typical highway bridges (Figure 5). Due to the sensitive nature of prestressed concrete beams to handling loads, plain reinforced concrete beams are preferred. Although slightly heavier and having reduced span ranges, they are more robust and resist attrition from wheel loading better than the prestressed box beams.

A further modification has been the replacement of the grouted shear connector with discrete welded shear connectors. Experience has shown that grouted shear connectors are sensitive to grout quality and where there is no wearing surface, they often break up. In addition to increased durability, the welded shear connector is also quick and easy to install, and suited to construction in below freezing temperatures. In over 15 years of widespread usage, we are not aware that any problems with weld fracture.

Recently the BCMoFR completed an investigation into the design of the welded shear connectors. Following the field evaluation of a number of bridges, the BCMoFR developed a design methodology and standard design details for single lane bridges using welded and grouted shear connections.

Figure 5
Welded Shear Connected Slab Girders

4.3.3 Bridge Railing

The typical industrial bridge curb rail consists of side-mounted timber rails approximately 0.50 m high. However, the BCMoTI requires the use of PL-1 crash tested barriers. Given the thin deck edge, side mounting rail barriers is not possible on the precast concrete deck panels. Therefore, designs incorporate a top mounted post on a widened deck panel (Figure 6). This change has allowed the BCMoTI to adopt already detailed and crash tested top mounted bridge rails.

Figure 6
Top Mounted PL-1 Railing

Often on fisheries sensitive streams, regulatory authorities mandate the use of full height curbs to prevent run-off entering the stream. The precast deck panels are easily modified to accommodate a curb and associated railing. A further advantage of the concrete curb is that a tubular PL-2 rail can be mounted on the curb with posts at 10’ centres that match typical concrete deck panel lengths (Figure 7). This result in an economical railing design with a single post per deck panel.

Figure 7
Top Mounted PL-2 Bridge Rail (posts at 3.048 m centres)

For precast concrete beams, side mounted PL-1 barriers are easily incorporated using accepted crash-tested details.

Where it is acceptable, owners could consider the use of TL-1 or Tl-2 barriers as described in AASHTO. The Ministry of Transportation in Ontario has recognized this and included guidelines for the use of TL-1 and TL2 barriers in the MTO Bridge Design Manual.

5.0 Typical Bridge Construction

Construction equipment is limited to only that strictly necessary for the bridge installation. This normally includes two excavators unless a crane is required for pile installation.

Excavators positioned on each side of the crossing install the substructure and then lift or skid the superstructure into place. For longer span steel structures, launching is possible using a temporary nose and the precast concrete deck panels as counterweights (Figure 8).

Figure 8
Typical Girder Launch

By designing the steel girders to support a construction load that includes the weight of an excavator carrying the heaviest precast concrete element, the same excavator used to construct the abutments can place the precast panels (Figure 9). To protect the deck, the contractor places plywood along the track centers. Once all the panels are in place, the contractor grouts the joints and pockets.

Figure 9
Placement of Precast Concrete Deck Panels

6.0 Procurement of Low Volume Road Bridges

In addition to adopting standardized conceptual designs to facilitate more economical detailed design, fabrication and installation, the BCMoTI also considers various procurement methods to suit each project. This flexibility allows projects to be tailored to specific circumstances. Generally, the process follows the following steps:

a) **Procurement of a site plan and crossing data:** The BCMoTI retains a consultant or suitably qualified person to survey the crossing, generate a site plan and collect channel information to facilitate the completion of any required hydrotechnical investigation.

b) **Assessing the operational and engineering risk:** This includes determining the appropriate level of investigation and study that is required by each discipline that will be utilized in preparing the design for a particular crossing. These include:

  - Assessing whether an LVR structure is appropriate.
  - Assessing the acceptable length of closure.
  - Deciding on whether a geotechnical investigation is required to verify the design of the bridge substructure or can a sufficiently robust substructure be designed at nominal extra cost without the additional information.
  - Deciding the required level of hydrotechnical investigation, i.e., is a simple open channel flow calculation acceptable or is a more detailed HECRAS analysis required.

c) **Decision on which (if any) risks are to be absorbed by the BCMoTI:** Quantifying and managing risks associated with the structure in a reasonable way is vital, and as an owner, it is necessary to be willing to accept appropriate levels of risk, especially with regards to operational issues. As an example, this often involves accepting minor settlements on gravel approach roads due to the availability of limited geotechnical information. However, since a gravel road is typically regularly graded, the costs associated with regrading the bridge approaches are already included in the road maintenance contract and therefore, there is limited additional risk.

d) **Determining the delivery method:** The purpose for considering LVR bridges is to provide flexibility to owners in the way they deliver these structures. Some strategies the BCMoTI has adopted include:

  - Purchasing the superstructure separately often results in savings ranging from 5% to 15%, depending on the project size since the contractor does not have to finance the purchase of the structure. This strategy also opens the bridge installation field to smaller qualified contractors who may not have the financial means to participate in these projects. By increasing the pool of qualified contractors, the BCMoTI is also receiving more competitive bids for the bridge installation.
  - Preparing and structuring projects so that bridge contractors build bridges and road contractors build roads, results in contractors completing the work that they are qualified to complete, while minimizing sub-contracting and the resulting additional costs.
  - Providing detours and work access to the contractors, so they can concentrate on bridge construction rather than traffic control, property access and public relations, which the BCMoTI staff become responsible for.

e) **Preparation of conceptual design (General Arrangement and installation drawings):** A consultant or in-house design team develop the conceptual design using some of the standard components previously described. These drawings clearly identify horizontal and vertical alignments, soffit clearances, and pier and abutment types and locations. Since a third party (often the fabricator's engineer) completes the detailed design, the conceptual design (or associated contract documents) must clearly identify the scope of works to minimize the risk assumed by the design engineer. Further, the conceptual design requires a complete review by the owner to ensure all the parts will fit. This is critical as two independent parties are often involved in the supply and construction.

f) **Procurement of the superstructure:** In British Columbia, the detailed design, supply, fabrication, and delivery of the superstructure is procured on BCBid©. This often allows the schedule to be reduced by at least four weeks if the installation contract is tendered at the same time. Generally, the components include the entire super and substructure for spread footing designs or all components above pile cut-offs for piled substructures. For crossings with piled foundations, the installer is required to supply and install the piles. The BCMoTI or the engineer responsible for the preparation of the conceptual design review the shop/fabrication drawings to ensure that all the pieces will fit.

g) **Procurement of the installation contract:** In British Columbia, major and minor works contracts are advertised on BCBid©. By splitting the supply and installation contracts, the BCMoTI can take advantage of scheduling the project over two fiscal years to avoid budgetary and cash flow constraints.

h) **Installation:** Some of the strategies adopted by the BCMoTI in the delivery of the installation of LVR bridges include:

- The Special Provisions in the supply and the installation contracts contain language directing the supplier and the installer to coordinate the delivery of the superstructure parts.
- Scheduling bridge installation during winter months, and completing road works in the following summer. Although counter-intuitive, this strategy often represents a saving of approximately 10% and allows contractors to retain staff over the entire year, ease their cash flow during slow season, and improve their employee retention and competency. LVR bridges generally lend themselves to winter construction, even when considering the additional costs associated with hoarding and heating cast-in-place concrete. As well, winter construction generally provides benefits recognized by the environmental agencies, since sedimentation control and clean-up is easier and access over frozen rivers is often not seen negatively by the agencies. Notwithstanding these positive aspects, it is often not possible to install the approaches until the summer since the ground is frozen. To this extent, the Northern Region of BCMoTI has successfully used a sacrificial concrete approach slab on Highway 16, and gravel approaches on secondary roads which are re-installed during the summer months.

i) **Certification by BCMoTI:** Given the alternative delivery methods, the Regional Bridge Engineer for the BCMoTI generally acts as the coordinating engineer of record for the project.

7.0 Sample Low Volume Road Bridges Recently Constructed in Northern British Columbia

Table 1 briefly details some recently complete Low Volume Road Bridges in Northern British Columbia. Each bridge listed was delivered using the modified processes described in the previous Sections.

Table 1
Sample Low Volume Road Bridges

Hargreaves Bridge	
Scope:	Replace existing log stringer with new structure onto existing bin wall. Road closed, no detour. 
Description:	12.2 m non-composite steel/concrete bridge, concrete spread footing and ballast wall, PL1 railing (thrie beam).
Length:	12.2 m
Width:	4.8 m
Traffic:	ADT << 10
Speed:	50 kph
Construction Schedule:	December
Duration:	2 days
Installation Cost:	$16,000 included demolition of existing bridge and installation of new bridge.
Superstructure Cost:	$60,000, included design, fabrication, and shipping f.o.b. of structure, railing, and footing.
Environmental:	Sedimentation plan required; no in-stream work.
Engineering/Supervision:	BCMoTI prepared prescription and procured bridge; no geotech investigation; engineer visually confirmed bearing condition; final inspection at completion; in-plant inspection by BCMoTI consultant.

Emperor Bridge

Scope:	Replace existing Bailey bridge; Road closed, no detour, pedestrian access only; delivered as a partnership (proponent was Kinder Morgan); BCMoTI provided design criteria and reviewed design; public relations and communications were handled by BCMoTI.
Description:	60 m, two span, single lane structure, PL2 rail; Low chainage abutment and pier are on rock; high chainange abutment is spread footing on existing road fill.

Length:	60 meters
Width:	5.8 meters
Traffic:	ADT(winter) < 10; ADT(summer) < 100
Speed:	50 kph
Construction Schedule:	October
Duration:	14 days
Delivery Cost:	$900,000, included design, geotech, project management, site supervision, supply and installation contract.
Environmental:	Sedimentation plan required; no in-stream work.
Engineering/Supervision:	Detailed design, project management, and supervision by Associated Engineering; final inspection at completion by BCMoTI engineer; in-plant inspection by BCMoTI consultant.

Hasler Bridge

Scope: Replace existing 70 meter three span Bailey Bridge. Detour installed by BCMoTI on old road alignment during July fish window. Public relations and communications through BCMoTI.

Description: 90 meter, continuous, three span composite steel/concrete structure on piled foundation, sidewalk. Extremely poor ground conditions (762 dia. piles driven to 45 meter penetration). Work adjacent to high pressure gas lines and three oil transmission lines.

Length:	90 meters
Width:	7.05 meters
Traffic:	ADT ~ 350
Speed:	50 kph
Construction Schedule:	February to March
Duration:	8 weeks (installation)
Installation Cost:	$900,000 included demolition of existing bridge and installation of new bridge, and the supply and installation of the piles.
Superstructure Cost:	$900,000, included fabrication, and shipping f.o.b. of entire structure.
Design Cost:	$200,000, included detailed design, environmental assessment and geotechnical engineering.
Environmental:	Sedimentation plan required; in-stream work using river ice and work bridge, navigable river.
Engineering/Supervision:	BCMoTI procured survey and design by consultants; BCMoTI procured superstructure by BCBid. BCMoTI tendered installation contract; In-plant inspection of superstructure by BCMoTI consultant; full-time site supervision by BCMoTI contracted consultant.

Newtown Bridge

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Scope:	Project was partnered with DFO and MoE. Replace existing blocked culverts with bridge, and reconstruct 50 meters of stream bed and 300 meters of road. Road closed, no detour.
Description:	Single lane, non-composite steel girder/wood deck bridge on post and pad spread footings, wood/steel tube wheelguards.
Length:	30.48 meters
Width:	4.3 meters
Traffic:	ADT << 10
Speed:	30kph
Construction Schedule:	October
Duration:	5 days
Installation Cost:	$70,000 included removal of culverts, reconstruction of stream and road, and installation of new structure.
Superstructure Cost:	$130,000, included design, fabrication, and shipping f.o.b. of superstructure and footings.
Environmental:	Sedimentation plan required; in-stream work.
Engineering/Supervision:	BCMoTI prepared prescription and procured bridge; BCMoTI procured general arrangement by consultant; Geotech engineered footings; hydrology provided by DFO; full time site presence by BCMoTI employees; final inspection at completion; in-plant inspection by BCMoTI consultant.

Peavine Bridge

Scope: Replace existing two span timber stringer bridge with 12 meter solid slabs on Highway 52; single lane traffic maintained by constructing one lane at a time; designated 85 tonne load route.

Description: 12 meter solid slabs with welded shear connectors, integral cap and wing walls, pile foundation, PL1 railing.

Length:	12 meters
Width:	8.4 meters (two-lane LVR Bridge)
Traffic:	ADT ~ 350
Speed:	80 kph
Construction Schedule:	November
Duration:	7 days
Installation Cost:	$50,000 included demolition of existing bridge, installation of new bridge one lane at a time, and supply and install piling.
Superstructure Cost:	$87,000, included design, fabrication, and shipping f.o.b. slabs, abutment caps, railing, and transition barriers. Additional costs of traffic control, approach barriers, small retaining wall, and paving $100,000.
Environmental:	Sedimentation plan required; no in-stream work.
Engineering/Supervision:	BCMoTI prepared prescription and procured bridge through BCBid; Geotech engineering by BCMoTI; full time site supervision by BCMoTI; traffic management by BCMoTI contractor; final inspection at completion; In-plant inspection by BCMoTI consultant.