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FINAL REPORT

DEVELOPING COST EFFECTIVE PLANS FOR LOW VOLUME BRIDGES

W. M. Kim Roddis, Ph.D., P.E.

The University of Kansas
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7 Author(s) W. M. Kim Roddis*, Ph.D., P.E. Assistants: Michael Ingalls, Kyle Hoppes and Malte von Ramin *Currently affiliated with George Washington University		**8 Performing Organization Report No.**
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16 Abstract

There is currently an escalating concern across the state of Kansas with respect to the age and condition of low volume bridges and methods available to modify or replace them. A high percentage of low volume bridges in the state of Kansas require or will soon require replacement. Local governments are incapable of funding the sheer number of the required bridge replacements or rehabilitations. These low volume bridges are classified in the same fashion as bridges on major state routes; however, the funding for local projects is much different than the funding for state projects. The local governments, cities and counties, are experiencing troubles raising the funds to pay for the design and construction of new bridges. State projects are roughly paid through an 80/20 split between federal and state funds. Federal funding for local projects must be blanketed over a much larger number of feasible projects, and the local governments are responsible for more than twenty percent of the total project cost. For the smaller counties in the state, annual revenue is extremely limited. As a result, fewer projects can be funded. To aid in the solution, this report is intended to inform Local Public Authority decision-makers of the process required in developing bridge plans and constructing bridges and culverts.

Kansas statutes require an engineer to be licensed when making decisions involving the health, safety and welfare of the public. Further, the statutes require that every county employ a licensed engineer, whose title shall be "county engineer." However, many counties are not employing a county engineer. Further information on the duties of a County Engineer may be found in report K-TRAN: KU/KSU-03-3, "A Study of the Duties of a County Engineer in the State of Kansas."

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Prepared by

W. M. Kim Roddis, Ph.D., P.E.

With Assistants:
Michael Ingalls
Kyle Hoppes
Malte von Ramin

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PREFACE

The Kansas Department of Transportation's (KDOT) Kansas Transportation Research and New-Developments (K-TRAN) Research Program funded this research project. It is an ongoing, cooperative and comprehensive research program addressing transportation needs of the state of Kansas utilizing academic and research resources from KDOT, Kansas State University and the University of Kansas. Transportation professionals in KDOT and the universities jointly develop the projects included in the research program.

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ABSTRACT

There is currently an escalating concern across the state of Kansas with respect to the age and condition of low volume bridges and methods available to modify or replace them. A high percentage of low volume bridges in the state of Kansas require or will soon require replacement. Local governments are incapable of funding the sheer number of the required bridge replacements or rehabilitations. These low volume bridges are classified in the same fashion as bridges on major state routes; however, the funding for local projects is much different than the funding for state projects. The local governments, cities and counties, are experiencing troubles raising the funds to pay for the design and construction of new bridges. State projects are roughly paid through an 80/20 split between federal and state funds. Federal funding for local projects must be blanketed over a much larger number of feasible projects, and the local governments are responsible for more than twenty percent of the total project cost. For the smaller counties in the state, annual revenue is extremely limited. As a result, fewer projects can be funded. To aid in the solution, this report is intended to inform Local Public Authority decision-makers of the process required in developing bridge plans and constructing bridges and culverts.

Kansas statutes require an engineer to be licensed when making decisions involving the health, safety and welfare of the public. Further, the statutes require that every county employ a licensed engineer, whose title shall be "county engineer." However, many counties are not employing a county engineer. Further information on the duties of a County Engineer may be found in report K-TRAN: KU/KSU-03-3, "A Study of the Duties of a County Engineer in the State of Kansas."

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1.1 Problem Statement

A significant percentage of bridges in the state of Kansas require or will soon require replacement. A large percentage of the bridges that require major rehabilitation or replacement are owned and maintained by the counties that the bridges service. These minor collector or low volume bridges are classified in the same fashion as bridges on major routes; however, the funding for the two classifications is quite different. The local entities in the state of Kansas are experiencing troubles raising the funds to pay for the design and construction of new bridges. Currently the local governments are required to pay the full cost of preliminary design procedures. Purchasing right-of-way, relocating utilities, geology, and consultant design costs are all the local government's responsibility. The costs are then split 80% (federal bridge funds) to 20% (local government) for the actual construction of the bridge. The county or local government is ultimately responsible for greater than twenty percent of the total project cost. This limits the number of projects an individual county can undertake in a given year, and the aged bridge structures continue to deteriorate.

1.2 National Bridge Inventory and Rating System

The National Bridge Inventory (NBI) is a database on bridge conditions, covering each state and the District of Columbia. The NBI data only includes bridges that are at least twenty feet in length. The NBI definition of a bridge is any structure having a length more than 20 feet from face to face of abutments or end bents, measured along the roadway centerline [FHWA, 1995]. In Kansas, this is interpreted as 6.100 m (rounded to the nearest 5 mm) or more in length. Data from the NBI is published yearly [NBI 2002]. The annual summaries tabulate data by state, including a breakdown of the total number of bridges in the state into those owned by the state, those owned by the counties, and those owned by cities and local government institutions.

NBI data classifies each bridge in a state with a Sufficiency Rating (SF) as well as designating bridges that are Functionally Obsolete (FO) or Structurally Deficient (SD) [FHWA 1995].

1.2.1 Sufficiency Rating

The numerical rating of a bridge is based on its structural adequacy and safety, serviceability and functional obsolescence, and essentiality for public use. The structural adequacy and safety comprise up to 55% of the total rating, while the serviceability and functional obsolescence comprise up to 30% of the total rating. The essentiality for public use comprises up to 15% of the total rating. A numerical rating of 100 would represent an entirely sufficient bridge, while a zero rating would represent an entirely insufficient or deficient bridge.

Bridges and their components are assigned SF numbers ranging from 100 to 0. If a bridge earns a rating of greater than eighty, the bridge is considered sufficient for today’s traffic demands. If a bridge earns a rating of less than fifty, the bridge is ill equipped to handle the loads required by current specifications. A sufficiency rating between fifty and eighty indicates that the bridge could be in need of major maintenance or minor rehabilitation to adequately manage current load demands [TRR, 1991].

1.2.2 Functionally Obsolete

A bridge inadequate to properly accommodate the traffic due to inadequate clearances, either horizontal or vertical, approach roadway alignment, structural condition, or waterway adequacy, is defined to be Functionally Obsolete (FO). Bridges in this category could include narrow bridges. A functionally obsolete bridge is determined from the results of field inspection findings where an appraisal rating of 3 or less is calculated for the deck geometry, under clearance, or approach roadway alignment; or where an appraisal rating of 3 is calculated for the structural condition or waterway adequacy.

The FO designation covers a wide range of circumstances involving bridge geometry or location. It can also include problems encountered when a relatively sparsely populated area experiences a large population influx. Functional obsolescence can apply to the width of the roadway in general, the width of the roadway in comparison to the width of the approach slab, the amount of traffic over the bridge, or the size or weight of new traffic using the bridge.

1.2.3 Structurally Deficient

A bridge inadequate to carry legal loads, whether caused by obsolete design standards, structural deterioration, or waterway inadequacy, is defined to be Structurally Deficient (SD). Bridges in this category may include those posted to restrict load limits as well as those closed to all traffic. A structurally deficient bridge rating is determined from the results of field inspection findings where a condition rating of 4 or less is assigned to the deck, superstructure, substructure, or culvert and retaining walls, or where an appraisal rating of 2 or less is calculated for the structural condition or waterway adequacy. Any bridge classified as structurally deficient is excluded from the functionally obsolete category [FHWA 1995].

The SD designation does not automatically indicate that the bridge is incapable of carrying traffic. This designation simply signifies that the bridge should no longer carry the load for which it was designed. Most bridges are designed for a load considerably larger than the typical passenger car, pickup, or van. Bridges are designed for selected types of freight vehicles, or an envelope of freight vehicles. A bridge designated as SD may be capable of carrying substantial traffic, although not its larger original design load. A bridge that is a danger to the public will be taken out of service before causing injury to the general public.

1.3 Role of NBI Rating System in Funding

The NBI rating method is used by state DOT's to determine the bridges that qualify for federal funding. The SF categorizes bridges and their individual parts as adequate (80-100), in need of moderate rehabilitation (50-79), or in need of major rehabilitation. The data also indicates FO and SD designation of bridges.

An SF of 80 to 100 will typically coincide with an absence of an FO or SD designation. A Bridge with an SF in the 0 to 79 range but having no FO or SD designation usually indicates that the bridge system has a component that is largely deficient, but that state, local or other funds will be used to make repairs. Inclusion of an FO or SD designation with an SF in the 0 to 79 range indicates the bridge system qualifies for some degree of federal funding to aid in project costs.

In addition to the SF, FO, and SD information, another factor used in determining federal funding is known as the "Ten-Year Rule." If major construction has occurred within the last 10 years (regardless of funding) that structure is not eligible for federal bridge rehabilitation/replacement funding. Safety projects such as rail replacement, guard-fence and maintenance repair works are exempt. Concrete bridge deck overlays and widenings are considered major work.

To summarize, a bridge would normally be eligible for federal bridge rehabilitation funds if the "Ten-Year Rule" does not apply, the bridge is designated as either "Functionally Obsolete" or "Structurally Deficient", and the bridge's sufficiency rating is less than 80. A bridge would normally be eligible for federal bridge replacement funds if the "Ten-Year Rule" does not apply, the bridge is designated as either "Functionally Obsolete" or "Structurally Deficient", and the bridge's sufficiency eating is less than 50.

1.4 Bridges in the State of Kansas

In the state of Kansas, the state maintains only 19.5% of the total number of bridges while individual counties maintain the other 80.5%. In terms of sufficiency rating, there are only 22.1% of the county bridges in the state that are adequate for current demands and that do not require rehabilitation or strengthening. These numbers rank Kansas as fourth in the nation in the percentage of bridges maintained by individual counties and near the national average of bridges maintaining an SF of above 80 [TRR, 1991].

Data is shown in Figure 1-1 for selected Midwest states, along with the mean values for the Midwest and Northeast. It is clear that a high percentage of county bridges in the state of Kansas require some sort of rehabilitation or full replacement. The values included in the graph have been taken from a table provided in the TRR No. 1291, Volume 1, and "Fifth International Conference on Low-Volume Roads, 1991".

Table 1-1 and Figure 1-2 show data from the NBI for Kansas, with data from Missouri and Iowa included for comparison. Since the NBI is limited to bridges at least 20 feet in length, this data, while useful, may not reveal the gravity of the situation facing counties. The current number of bridges for the state of Kansas casts an unpromising outlook on the state from an engineering standpoint and also from a revenue standpoint. However, the current NBI data should not cause alarm with respect to the safety of motorists in the state of Kansas.

1.5 Validation

Current National Bridge Inventory (NBI) data confirms the circumstances that most of the counties are experiencing with respect to older bridge structures in service along many rural routes in the state of Kansas. The bridges under consideration have spans typically under two hundred feet, have low average daily traffic counts, but exist as vital routes for local residents. Counties are currently weighing the available options concerning these low volume bridges. Presently, the options available are replacement, rehabilitation, or removal of the bridges.

Removal of only a few of the rural route bridges in each county will result in long delays for commuters that use the route year round, and for freight or grain trucks that use the route seasonally. Delays are costly both directly and indirectly. The commuter will experience the added miles (direct cost) and added time (indirect cost) to travel to and from work. The farmer that uses the route seasonally will be forced to choose a less direct route to the grain elevator. This will add man-hours to each field harvested and it will increase the miles traveled for each vehicle used. This will directly affect the profit that each field will produce. This is an option that the state and the counties are working to avoid.

Rehabilitation is feasible only for some of the newer structures. The aged bridge structures were designed for much lighter loads. Many of the older bridges with structural deficiencies would require rehabilitation of superstructure and substructure alike. Bridges that are functionally obsolete typically need a wider roadway or a larger waterway opening, so they would also require rehabilitation of both the superstructure and substructure. It is counter-productive to rehabilitate an entire structure to improve its load capacity only slightly. Since the design life of many of the structures has been reached or exceeded, rehabilitation is not an economical solution.

Replacement of the structures is the logical solution to the problem of these aged structures. Designing and building better bridges to last more than fifty years is the county's only real option. However, bridge design and construction are expensive.

This report briefly explains the major components of bridge design including preliminary surveying of the streambed, geology data, hydraulics, substructure selection and design, superstructure selection and design, and channel preparation. The report also suggests areas that may be of interest with respect to further research or development.

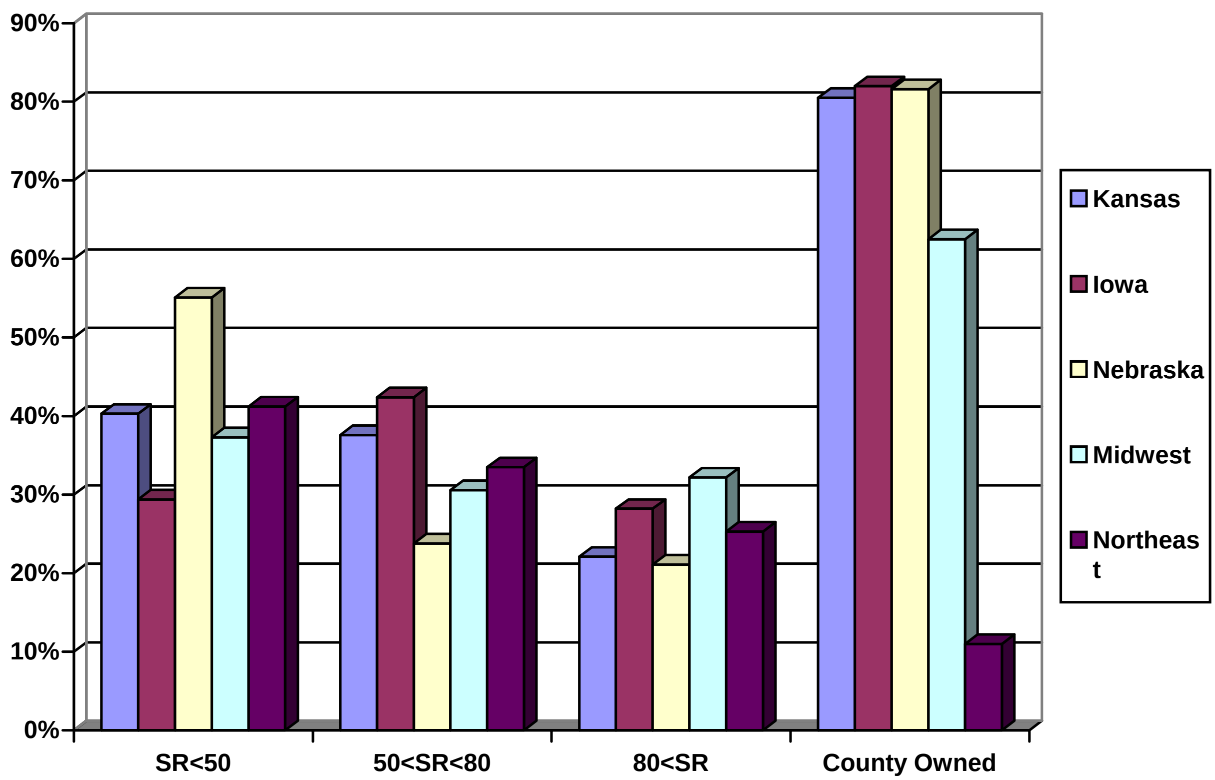

Figure 1-1: Sufficiency Rating of County Bridges

(TRR No. 1291, Vol. 1, 1991)

Table 1-1: State and County Totals

	2000 TOTAL		1997	1998	1999	2000	COUNTY %
Kansas	25917	Total SD/FO Percent	20869 6256 30.0%	20923 6134 29.3%	20798 5916 28.4%	20645 5739 27.8%	79.7%
Missouri	23367	Total SD/FO Percent	13357 6412 48.0%	13278 6194 46.6%	13293 5897 44.4%	13443 5615 41.8%	57.5%
Iowa	25070	Total SD/FO Percent	21190 6697 31.6%	21118 6672 31.6%	21057 6593 31.3%	21014 6632 31.6%	83.8%

Source: Better Roads, 1997-2000

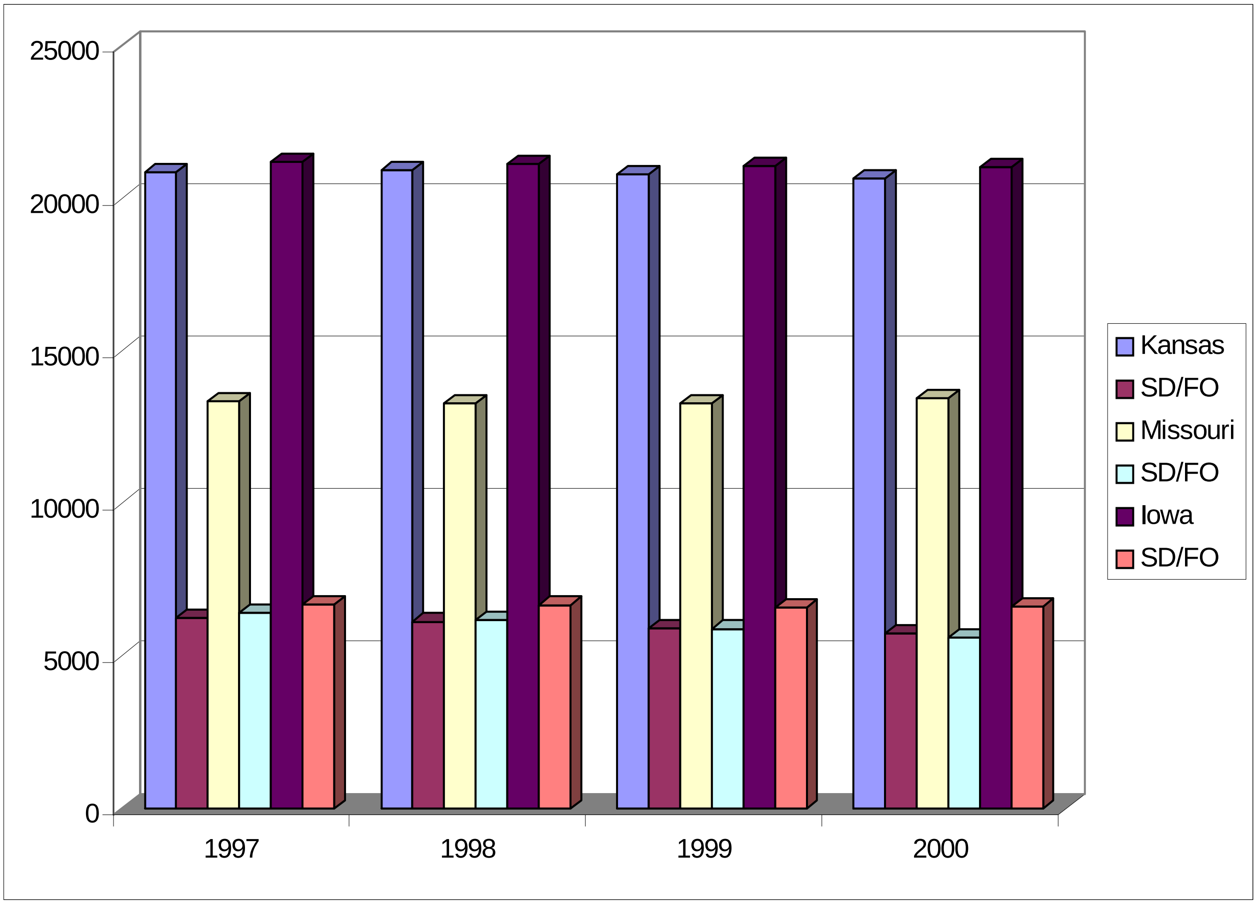

Figure 1-2: Chart of Current NBI Bridge Ratings

[Better Roads, 1997-2000]

Chapter 2

Elements of the Design Process

2.1 Bridge Design Costs

To provide insight into what is paid for under design costs, this chapter provides an overview of the bridge design process. Bridge design is a process that requires input from a number of diverse disciplines.

Bridge design requires the services of a licensed Professional Engineer. Although there are costs associated with design, it is a false economy to strive to limit overall project costs by skimping on design costs. The design costs are small compared to the construction costs. Major costs may be incurred by inadequate investment in the design process. If any given stage of the design process is not done properly, the end result may well be a bridge with minor or major maintenance problems. If each stage is given proper attention and the design procedure is carried out correctly, the end result is a bridge that will last, and a bridge that will require the least amount of maintenance or repairs.

Kansas statutes require an engineer to be licensed when making decisions involving the health, safety and welfare of the public. Further, the statutes require that every county employ a licensed engineer, whose title shall be "county engineer." However, many counties are not employing a county engineer.

Table 2-1 provides a generalized breakdown of the costs of the various design components. Through discussion with a few of the consultant firms that design bridges for county projects, similar percentages of the overall design fees were given. The percentage of overall design cost gives some indication of the amount of time and effort that is dedicated to each design component. This generalized list, in some cases, belies the importance of the design item, discussed in more detail below.

Table 2-1: Generalized Breakdown of Design Costs

Design Component	**Percentage of overall design cost.**
Geology	5-15%
Survey	20-25%
Hydraulics	20-25%
Roadway and Geometry (safety)	15-25%
Superstructure	10-15%
Substructure	15-20%
Environmental & Permits	Varies

2.2 Geology

Geological exploration of a typical bridge site, essential to the design of the substructure, determines information concerning the susceptibility of the soil to erosion/scour during high water flow and the amount of settlement the approach embankment will undergo. The exploration also aids in determining the depth of the substructure foundations necessary to carry combinations of loading. An error in this stage of the design procedure may result in a minor repair to prevent more severe scour damage, or a major repair that requires completely redesigned and reconstructed abutment or pier foundations. The percentage of total project cost is relatively low for the geology exploration, but the cost of errors made due to inadequate exploration can lead to large costs to the owner over the design life of the structure.

The KDOT Bureau of Materials and Research Geology Manual specifies drilling procedures [KDOT GEO, 2000][KDOT BLP, 2005]. The minimum number of borings recommended for design at each construction site is dependent on location, topography, lithology, general terrain conditions, and the information gathered in each hole drilled at the site. In a case where the differential depth of a layer of soil is greater than five feet, an intermediate boring is required to authenticate a centerline soil profile.

Surface data and accurate “as built” plans can reduce the number of borings required at the site and can considerably aid in establishing the centerline soil profile [Koontz, 2001]. In western Kansas, in varying degrees from North to South, a bedrock layer will typically be significantly below the soil surface. In eastern Kansas, a bedrock layer is normally obtainable at a reasonable depth. For areas in central Kansas, the knowledge and experience of the geologist is relied upon to determine the depth of a bedrock layer.

Typically one boring is required at the bottom of the channel, at each pier location and at each abutment along the centerline of the bridge. Site topography and terrain may be such that additional borings are required perpendicular to the centerline of the bridge. This process will provide a representative geologic profile along the centerline of the bridge.

The geology report is expected to include an analysis of the data obtained in the borings and the pile bearing capacity based on typical types of supports (pile, drilled shaft, or footing foundations). Additional information is included in the report explaining solutions to unexpected situations, materials, or conditions that may be encountered. The Geotechnical Engineer’s experience and expertise are heavily relied upon when problems or situations arise on site.

2.3 Survey

The site survey, while only a minor design cost, can have a significant effect on the final project cost. Properly locating the existing right-of-way, correctly characterizing the channel cross-section, and gathering the historical site information all contribute to a bridge that will appropriately match the characteristics. Errors made in the site survey could result in utilities relocated onto private property, an error in the sizing of the bridge for construction purposes, or an error in sizing the bridge for the site hydraulics which may cause higher backwater elevation and flooding or higher stream velocity which will cause additional scour of the foundations. All would add notably to the life cycle cost of the structure, and could cause unintended property damage to local residents, injuring the relationship between taxpayers and their government.

Surveying the site is essential to properly locate the bridge elements, and to gather necessary information on site characteristics for hydraulic design. Each site varies in the amount of time devoted to the survey of the channel sections, streambed profiles, roadway profile, and waterway opening. [KDOT SUR, 2005]

As a minimum, the survey will include a general examination whether insurable buildings or structures are located upstream of the bridge. The survey information required then branches into two basic areas. These two areas include the hydraulic survey and the site grading.

Beginning with the site grading or the actual location of the proposed or existing bridge, surveys are taken to glean information about the topography of the road leading up to the bridge perpendicular to the road. Sections will be taken, typically, at the location of the abutment, and at increments of 25’ measured from the abutment out to 100’ from the intersection of the approach slab and the abutment. This information is also used in the hydraulics analysis to determine the location that overtopping will first occur.

The hydraulics survey, in its most simple situation, is much more complex, and will be the deciding factor in determining the required bridge size. If insurable structures are located upstream or downstream of the proposed bridge, the survey will require much more time, and considerable engineering judgment. The minimum amount of information will include one section at one bridge length upstream and downstream of the bridge, and at the upstream and downstream face of the existing structure. Additionally, the surveyor will assess historic high water information from the county engineer, the road superintendent, and nearby landowners. This includes information about the elevation of the high water, the frequency of the occurrences, and the frequency of the road getting put out of service by water overtopping it. Photographs are taken from a location on the existing structure facing upstream and downstream to aid the engineer in estimating the hydraulic roughness coefficients that will affect the flow in the channel. The hydraulic analysis depends heavily on the survey of the site, and it will be verified and/or validated by the information received from the local residents and county employees [Reynolds, 2001].

The survey process becomes more critical and more complex with additional drainage area, floodplain regions, and with more populated areas. If insurable structures are located in the vicinity of the proposed bridge, then loss of property or loss of life becomes more apparent. The designer, in this case, will require additional cross sections both up and down stream and the analysis will necessitate a more detailed approach to prevent losses.

2.4 Hydraulics

Mistakes in the hydraulic design of the site can cause considerable damage to residents upstream of the bridge, residents downstream of the bridge, or to the bridge itself, decreasing its expected lifespan. Miscalculations in the analysis or inaccurate information in the previous stages of the design will affect the proposed backwater elevation, the proposed bridge size, and the velocity of the flow during peak high water and normal high water at the location of the bridge and downstream of the bridge. Damage to private property could result and the trust or relationship between the public and the local government could also be damaged.

Hydraulics design is dependent upon correct, thorough geological information, and is also very dependent upon the information gathered from surveying the construction site.

The preliminary hydraulics design begins with a standard topographical map in order to determine the area of the surrounding landscape, upstream from the bridge, which will contribute to overall drainage. This is known as the contributing drainage area (CDA). The CDA is used in the analysis of the site hydraulics and is also used in determining whether a permit will be required from the Department of Water Resources (DWR) and/or the Army Corp of Engineers [Brunkow, 2001].

United States Geological Survey gauging stations are also referenced in the preliminary hydraulics design (see USGS map of Kansas streams and rivers). The USGS information is another source to verify the typical flow of most “blue line” streams. A blue-line stream is simply a stream or river that currently or has had significant flow and has been designated on the USGS maps as a solid or dashed blue line (Figure 2-1) [Brunkow, 2001]. This is also used as a preliminary design check on the engineer’s analysis of the preliminary site conditions.

The analysis of the site and surrounding CDA is then carried out. There are several different analysis programs available, as well as design aids and various methods and equations to aid an engineer in carrying out the analysis. Incorrect or obsolete information obtained in the preliminary stages affects the final solutions to varying degrees. The information obtained in the analysis is then used to size the waterway opening, determine the required structure size, determine the required size or depth of pier foundations, determine the backwater elevation, and to determine the downstream flow and velocity. Each of these factors is essential to the final product of a well-designed structure. Much of this information is also required for obtaining permits from the DWR, Army Corp of Engineers, Department of the Environment, the Coast

Guard if the river is navigable, and many other government departments depending on site-specific details.

The Bureau of Local Projects has released Memo 93-9 [KDOT BLP, 1993], which modifies hydraulic design procedures in the case of county projects. Often, the stream crossing structures are designed for a ten-year frequency with respect to overtopping. This is considerably below the fifty or one hundred year overtopping frequency that city or state system bridge structures are designed to withstand. The frequency that overtops either the approach roadway or the bridge itself is considered to be the actual design frequency of the structure. In the case of many counties in central or western Kansas, roads wind through a floodplain. During flood conditions, the road may overtop at five-year frequencies and building a bridge to endure ten-year flow frequencies would be less than economical.

Many factors affect the hydraulics analysis, and some may affect the actual acceptable design frequency. Roadway geometry and elevations, as discussed, may affect the true design frequency of the bridge according to the KDOT Bridge Manual [KDOT BR, 2006], regardless of the frequency the bridge is designed to withstand. Site topography and soil permeability (Figure 2-2) [USGS, 2000] determines the effective CDA and the amount of water that will drain to the streambed of the bridge under consideration. The design frequency flow will be determined via the KDOT Bridge Manual [KDOT BR, 2006] or BLP Memo 93-9 [KDOT BLP, 1993], depending on the location and funding of the bridge, to determine the size of the waterway opening. Through the analysis of the natural valley, the existing structure, and the proposed structure, the engineer will determine the environmental issues, backwater elevation, the stream velocities, and the effects of scour. After the engineer determines this essential information, the engineer must use what the bridge manual describes as “an evaluation of reasonableness” to determine the actual design frequency of the bridge.

> “Under the reasonable use rule, a possessor of land is legally privileged to make a reasonable use of his land even though the flow of surface waters is altered thereby and causes some harm to others. The possessor of land incurs liability, however, when his harmful interference with the flow of surface waters is unreasonable. The issue of reasonableness or unreasonableness is a question of fact to be determined in each case upon consideration of all relevant circumstances. In determining the question of reasonableness under the reasonable use rule, it is proper to take into consideration such factors as the amount of harm caused, the foreseeability of the harm which results, the purpose or motive with which the possessor acted, and other relevant matters such as whether the ability of the possessor's use of his land outweighs the gravity of the harm which results to his neighbor from alteration of the flow of the surface waters.” (AASHTO 1987)

When a structure is being replaced to reduce backwater elevation, the designer should reference study K-TRAN: KU-04-9 for Downstream Effects of Culvert Replacement [KTRAN, 2006].

2.5 Substructure Selection

For typical short-span, low-volume bridges, the ideal abutment is an integral abutment. This type of abutment may have a higher initial cost, but the cost savings over maintenance and repair of a freestanding abutment will be substantial.

2.5.1 Abutment Selection

Selection of the proper abutment can save owners on costly maintenance or repairs. The design of multiple, simple span structures must include a design for expansion devices. However, if a bridge has been designed with integral abutments and exceeds the recommended maximum length for continuous bridges, then other costly maintenance issues could occur.

Integral abutments are used on bridge lengths up to 400 feet, as recommended in the KDOT Bridge Design Manual [KDOT BR, 2006]. Integral abutments remove the need for an expansion joint between the bridge deck and the bridge backwall. Removal of the expansion joint device also removes the regular, recommended maintenance and repair of the device. For shorter bridge structures that are not as susceptible to thermal expansion, the integral abutment saves initial costs of the expansion device, yearly maintenance cost of the device, and inevitable future replacement costs. However, if an integral abutment is designed improperly for a structure that is vulnerable to excessive thermal expansion, then costly rehabilitation may be required. Many different situations may occur when an integral abutment is designated for the incorrect structure type or length. Piers and/or abutments may be subject to unintended deflection in terms of rotation or axial movements. Unintended deflections also entail unintended forces induced in the structure or movements in the soil that can translate into erosion complications.

Freestanding abutments are essentially separated from the bridge deck. The deck and girders are allowed to deflect in the longitudinal or transverse direction while the abutments are fixed in space. Forces are transmitted, ideally, only in the vertical direction, and bearing devices manage the reasonable movements of the bridge superstructure. The expansion joint device spans the gap that will form between the bridge deck and bridge backwall. There are many different types of expansion joints, and each should be considered carefully depending on the type of bridge, the amount of expansion and contraction expected, the types of vehicles that will travel the bridge, and the materials that will be present on the bridge during weather events.

Water, salts, chemicals, the environmental conditions, and obstructions all affect the correct operation of expansion devices. Failure of the expansion device can cause deterioration of the bearing devices, deterioration of the pier or abutment, and deterioration of the expansion device itself or the concrete surrounding the expansion device. If concrete spalls off around the expansion device, the device, or elements of the device can become detached from the deck and become a danger to pedestrians, motorists, and vehicles.

For short span applications, the additional expense of forming and constructing the integral abutment is minor in comparison with the costs associated with maintenance and rehabilitation of expansion devices.

2.5.2 Pier Supports

There are many different types of piers and pier foundations. Engineering experience and engineering judgment are essential ingredients in the decision making process for pier design. The engineer will take into account the best location for piers depending on normal high water flow, the best type of pier to be built with respect to backwater elevation and debris, and the ideal foundation for the piers and abutments to resist scour and resist various combinations of loading.

The geology report and survey reports are essential in the pier design process. Incorrect location of the piers with respect to the stream channel, or incorrect depth of the pier foundation could reduce the life of the structure considerably due to the possibility of failure of the foundation due to scour. An incorrect number of piers, whether to few or too many, may increase the cost of the structure considerably. By processing accurate data of the site surface and subsurface conditions, an engineer is able to arrange different span configurations and base the number of piers on a combination of substructure and superstructure variable costs.

2.6 Superstructure Selection

There are many different types of superstructures. In the state of Kansas, a reinforced concrete haunched slab is typically the most cost effective superstructure for short spans, based on cost per square foot, due to contractors' familiarity with this alternative. Outside of the achievable span lengths for haunched slab superstructures, the prestressed concrete beams and tees or post-tensioned haunched slab spans are similarly cost effective. Typically, steel superstructures are reserved for longer spans, but options such as Inverset® [Inverset 2001] can become cost-effective for intermediate spans. Primarily, the focus of superstructure selection is not on the type of existing superstructure, but the breadth of options currently available and how they correspond with the site and the span configuration.

2.6.1 Roadway Width

The Bureau of Local Project's Project Development Manual [KDOT BLP, 2003] offers many charts, tables, figures and guidelines for new structures or structures that will undergo rehabilitation or reconstruction. The design roadway width depends largely upon the width of the approaches on either side of the bridge, the overall length of the bridge, the road surface conditions, and the amount of traffic over the bridge in an average day. There are limitations on the surface conditions of the roadway with respect to the amount of traffic that travels the route. And there are several aspects of the design of the roadway, the right of way, the clear zone and the embankment slopes that an engineer will read directly from the tables provided.

The minimum roadway width that is allowed by the BLP Development Manual [KDOT BLP, 2003] is 26-feet wide. In bridge design, the design lane is 12-feet wide. The minimum 26-foot wide bridge does not allow for any future population expansion or an increase in traffic flow over the bridge. Farming tractors and implements are increasing in size, weight, and, of concern here, width. A farmer that uses a culvert bridge with no side rails to get from field to field, may be prevented from crossing an open bridge with safety barrier that only gives 26-feet of clear passage. So, adequate time needs to be devoted to estimating future increases in traffic, or future uses of the bridge being designed. A wider bridge does not necessarily need to be designed or constructed, but an engineer can design for future uses by considering future loads that will be transferred to the substructure and foundations. Increasing the size of the substructure slightly will increase the capacity considerably, with a minimum amount of cost compared to the complete redesign and construction of a bridge, substructure and superstructure, which could become functionally obsolete within a hypothetical fifteen years.

2.6.2 Span Configuration

For greatest economy, superstructure and substructure costs need to be evaluated on the basis of span lengths. Typically, as the span length increases the cost per square foot of deck area increases, and conversely, the cost of substructure increases with the number of piers constructed. Some sites will not allow many different span configurations due to site constraints, but it is useful and economical to investigate the possibilities available. Table 2-1 is a list of typical span lengths based on experience.

Whether the structure will be steel or concrete, the cost of superstructure, the bridge girders and bridge deck, will typically increase with the span length. Material, forming, falsework construction, and general labor costs will tend to increase with span length. There are charts available from fabricators or engineering firms that display the cost of superstructure versus the span length. Typically, this is nearly a linearly increasing line.

Substructure costs vary inversely to the cost of superstructure. The longer the spans the fewer piers required, and costs tend to go down for substructure. The graph of substructure costs versus span length is commonly a linearly decreasing line with increasing span length.

By simply adding the two cost basis together, the optimum span length will be at the lowest point of the roughly parabolic curve [Bethlehem, 1996], [NSBA, 1996], [Figure 2-3]. After arriving at the preliminary span length, the engineer would need to check this against the hydraulics analysis and the channel section survey information. If the pier locations do not interfere with site conditions and are not positioned in the center of the stream channel, then it could be a viable option. If the numbers of piers do not interfere with the hydraulics analysis of the site, provide a large enough waterway opening and do not raise the backwater elevation significantly, then the engineer may have a viable option for the bridge span configuration.

2.6.3 Abutment Details

The different styles of abutments, integral and free standing, have been discussed previously. There are also many details in the design of the abutment that provide adequate strength and are also economical.

Many aged bridges were designed with narrow waterway openings with high, vertical abutment walls. There are several reasons that this type of abutment is no longer used in typical bridge design today.

Labor costs have increased enormously since the 1930’s or the 1960’s, when this type of abutment was designed. The high, vertical wall is labor intensive and is not economical with consideration of today’s labor costs.

General hydraulics analyses have shown that by decreasing the area of the waterway opening, the velocity of the water through the opening increases. Scour of the material on the upstream and downstream side of the opening increases with an increase in velocity of the flow. By increasing the span length and specifying a standard compact abutment that will be well above the normal high water flow, the design results in several economical savings. The labor to construct a compact abutment is much less compared to the large abutment. The cost of labor required translating the height of the old abutment into span length is also considerably less than the cost of the large abutment. By increasing the span length and thereby increasing the area of waterway opening, the velocity of the flow under the bridge will decrease, which decreases the amount of scour that could occur at the piers. Decreased scour effects on the piers will translate into cost savings in the depth to the top of the foundation that would have been required under the large abutment walls. By repositioning the abutment out of the normal flow of water, the abutment will not be as susceptible to scour affects which translates to cost savings in the abutment foundation.

Wing walls for vertical abutments are large in order to make the stream crossing safe for motorists. The slope ratio controls the required length of the wing walls. The wing wall for an abutment that is six feet tall requires much less material and much less labor than an abutment that is twelve feet tall.

By repositioning the abutment up away from the flow of the stream and increasing the span length of the bridge, the abutment components, the amount of material required constructing the abutment, the labor required for construction, and the abutment details are all areas that the owner will perceive cost savings.

2.6.4 Rails or Barriers

For guidance on rails and barriers, see the AASHTO Roadside Design Guide [AASHTO, 2001]. Low volume roads may benefit from the possibility of removal of guardfence and bridge rails for low volume bridges. Studies have shown that for bridges spanning relatively shallow streambeds with reduced speed limits, there may be less risk for the motorist to be allowed to continue into the ditch rather than hit a concrete barrier or guardfence.

The designer/owner is still responsible to the motorist, however. Safety barriers and guardfence are placed to provide safety to the motorist, and reduce the possibility of loss of life. The designer must still go through a design process in order to substantiate the removal of the guardfence or barrier. Any rail used must be crash test approved by the FHWA.

2.7 Environmental and Permits

For any improvement, whether a bridge or road, the multi-disciplinary design professionals need to actively address environmental issues during plan development.

National Environmental Policy Act (NEPA) applies to all projects utilizing federal funds.

All proposed bridge structures or significant repair projects, shall have plans submitted to the State of Kansas. These plans, whether utilizing federal funds or not, are automatically routed for review to eleven environmental agencies per the Kansas Environmental Coordination Act.

Division of Water Resource permits are obtained from the Kansas Department of Agriculture in Topeka. Other permits which may be required include but are not limited to:

Army Corp of Engineers (section 404)

Kansas Department of Health and Environment

US Coast Guard (if the river is navigable)

US Fish and Wildlife

Other government departments depending on site-specific details

Other agencies which could comment and affect a permit and therefore plan cost and schedule are:

Kansas Wildlife and Parks

Kansas Historical Society

US Fish and Wildlife (whether permit required or not)

Table 2-2: Typical Span Lengths

Bridge or Superstructure Type (Continuous over piers)	Optimum Span Length	Optimum Girder Spacing
Cast in place Solid Slab	Up to 30’	N/A
Cast in place Voided Slab	30-70’	N/A
Cast in place P/T Slab	60-100’	N/A
Rigid Concrete Frame or Haunched Slab	30-70’	N/A
AASHTO Type II	30-60’	5-8’
AASHTO Type III	50-80’	5-8’
AASHTO Type IV	70-100’	5-8’
AASHTO Type V	90-120’	5-8’
AASHTO Type VI	110-140’	5-8’
Concrete Bulb Tee	120-130’	5-8’
Spliced P/T Bulb Tee	130-260’	5-8’
C-I-P P/T Box Girder Single Cell	150-750’	N/A
C-I-P P/T Box Girder Multi Cell	60-200’	N/A
Steel Composite Rolled Beam	30-80’	6-9’
Steel Composite Plate Girder	80-200’	6-24’
Steel Composite Box Girder	80-200’	6-12’ web spacing

Figure 2-1: Blue Line Streams

[USGS, 1998]

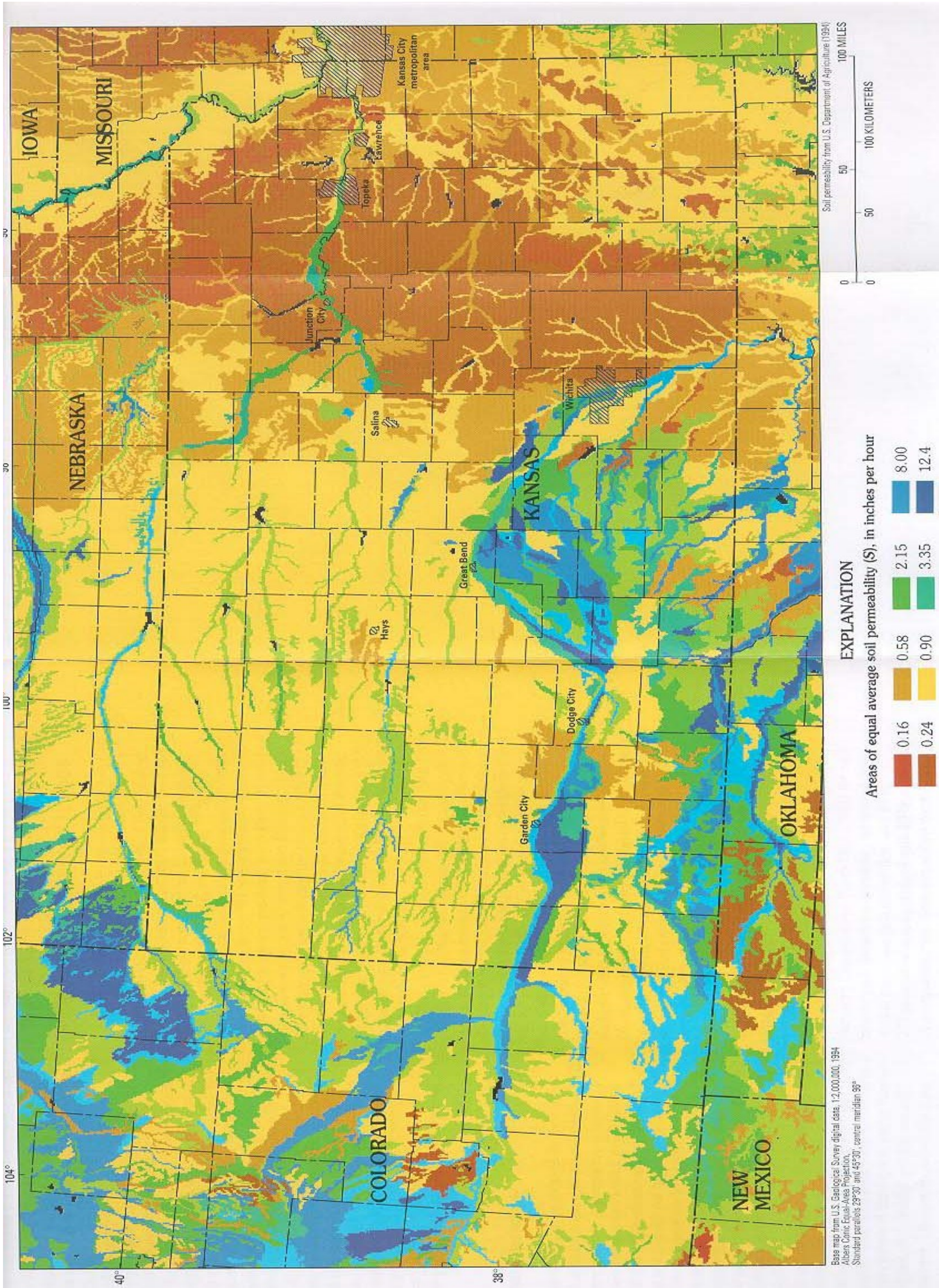

Figure 2-2: Soil Permeability, Kansas

[USGS, 2000]

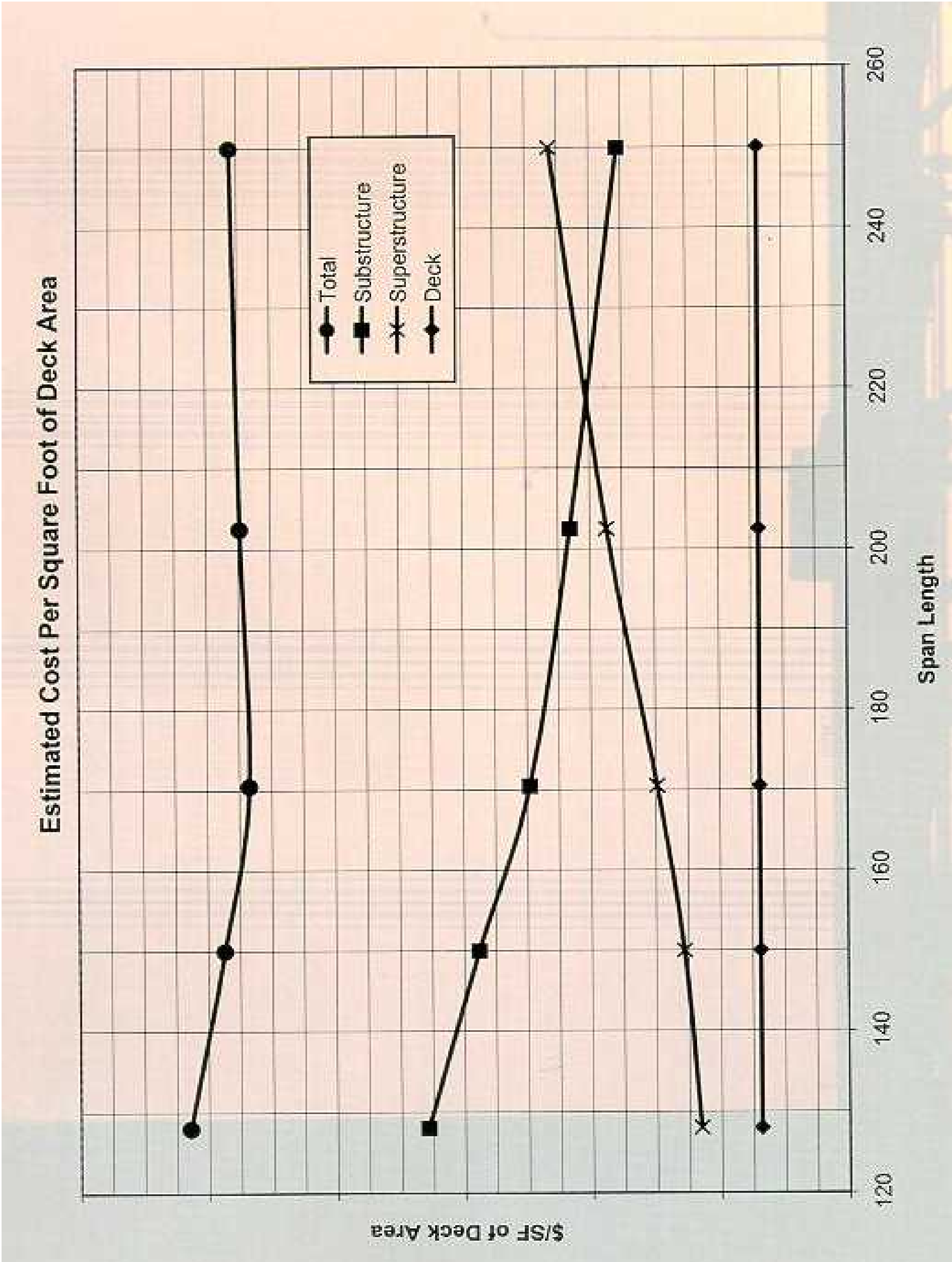

Figure 2-3: Span Configuration Qualitative Cost Analysis

[NSBA, 1996]

Chapter 3

Design Practice

3.1 Requirement for Professional Engineer

The use of KDOT standard drawings, or any other standard details, does not remove the need for a professional engineer to review and check the design plans for each specific bridge structure.

According to the Kansas State Board of Technical Professions, the designer of a bridge or culvert must have a current Professional Engineer's license in Kansas. This is the first requirement that must be met before design work can begin.

Overall functions of a County Engineer can be found in "A Study of the Duties of a County Engineer in the State of Kansas," by Mulinazzi, Gumpa, and Russell. In that report, a representative list of county engineering duties is included, which indicates whether the function requires an engineer's license or may be performed by a non-engineer? This list is not all-inclusive, but it provides information for a non-engineer to decide if an engineer should be involved in the decision-making process. Some consulting engineers support the availability of engineering services in each Kansas county because they could provide the service.

Specifically, that report lists the activities that require a licensed professional engineer as follows:

3.1.1 Engineering

- Establish standards for improvement projects such as bridges, culverts and roads
- Roadway and culvert design
- Bridge design for county crew construction
- Size culverts and bridges
- Bridge inspection and load ratings

- Compute drainage areas and runoff rates
- Determining repairs on bridges and culverts
- Drainage and flooding problems evaluations

3.1.2 Road and Bridge Construction

- Prepare state & federal permit applications
- Prepare contracts and deeds
- Prepare contract documents
- Construction inspection

3.1.3 Maintenance of Road Network

- Pavement management system

3.1.4 Planning and Zoning:

- Review new developments
- Review drainage studies
- Standards for new developments

3.1.5 Safety:

- Signing studies
- Signing policies
- Signing plans for projects and detours
- Investigate safety related complaints
- Evaluate speed limits

3.1.6 Other Duties

- Maintenance, training, budgeting, other administrative, etc

3.2 Kansas Department of Transportation Public Website

The official web site of the Kansas Department of Transportation is located at the url: www.ksdot.org. Many of the KDOT standard drawings are available online through this site.

Directions for navigating the website are given below:

- click on “Doing Business With Us”

Several links below “Doing Business With Us” are of interest for the purposes of this report.

These links, not necessarily show on the webpage in this order, are:

- **Information for Highway Contractors**: This includes a pre-qualified contractors list.
- **Information for Design Consultants**: This section contains bridge standard documents and checklists, haunched slab information, RCB standards, as well as standard documents.
- **Information for Local Government**: KDOT’s Bureau of Local Projects is under this heading. The Bureau of Local Projects is discussed in more detail below.

3.3 KDOT’s Bureau of Local Projects

The Bureau of Local Projects assists cities and counties in development of state and federal-aid projects. The Local Project Development Manual is available to county and city officials upon request. The manual is supplemented and updated by official “BLP Memos” that are sent to county agencies, city agencies and consultants for modifications to the project development process for local governments.

Funding information and category information for what projects are eligible for Federal funding assistance is available from the Bureau of Local Projects webpage by clicking on “Funding Information”.

3.4 Standard Drawings Available From Kansas Department of Transportation

There are many KDOT standard drawings that may be of interest to Design Consultants for bridge rehabilitation or replacement projects http://www.ksdot.org/burDesign/bridge/ . A list of the latest standard KDOT drawings is available on the KDOT website at http://www.ksdot.org/burdesign/standard_notes/main.asp . This is simply a list of the standard drawings and is a free service.

Requests for Reinforced Concrete Box Culvert (RCB) standard drawings for county and city projects are made to KDOT's Bureau of Local Projects. The RCB Details Request Form can be downloaded from the KDOT website, http://www.ksdot.org/burDesign/bridge/rcbinput.asp. The form can be used for submittals in both SI and USC units.

Access to the KDOT standard drawings themselves may be done through the ***Information for Design Consultants*** portion of KDOT's website. Clicking the link "Engineering Standards" provides a login screen for the KDOT Authentication & Resource Tracking (KART), requiring Design Consultant's company account "UserName" and "Password" to get to the files. A Design Consultant wishing to become a subscriber to KART may do so by accessing http://www.ksdot.org/kart/ .

Standard drawings are available through KART from KDOT's Bureau of Design for use by Design Consultants. Currently these standard drawings are available to consultants that request them. Entire bridge superstructures are available for haunched slab structures, and post-tensioned haunched slab structures. However, these complete plan details are available in only a few span configurations and roadway widths. As more of the structures are designed 'in house' at KDOT, in other span arrangements and roadway widths, additional complete structure details will become available to consultants and professional engineers.

The publication "Guidelines for Geometric Design of Very Low Volume Local Roads (<400 ADT)" addresses the unique design issues highway designers and engineers face when determining appropriate and cost-effective geometric design policies for very low-volume local roads. This publication is available through the American Association of State Highway and Transportation Officials (AASHTO) at:

AASHTO
444 North Capitol St., N.W.
Suite 249
Washington, D.C. 20001

or via email at https://bookstore.transportation.org/support.aspx or
https://bookstore.transportation.org/

Chapter 4

Cost-Effective Practices for Off-System Bridges

As the deterioration of aged bridges continues, the counties in the state of Kansas will be faced with closing rural routes. The sizes of the counties in the state of Kansas, unfortunately, are not flexible. The amount of revenue for each county, also, is not easily increased. Therefore, further attention needs to be devoted to either the areas of funding for county projects, the area of 'in house design' for county engineers, a modification or overhaul in the design procedures allowed, requirements for professional engineers to be on staff in each county, or any possible combination. These concerns are not limited to the state of Kansas, but instead reflect the nationwide need to encourage counties and cities to improve the overall sufficiency rating of their structure population.

Of particular interest is the National Cooperative Highway Research Program's (NCHRP) NCHRP Synthesis Topic 32-08 "Cost-Effective Structures for Off-System Bridges." This effort was a synthesis of the existing practices and processes used to satisfy reasonable operating standards for off-system bridge and approach roadways. State Departments of Transportation (DOTs), local agencies, and the literature are being surveyed to document the practices that lead to the most economical, safe and functional, off-system bridges. The above Topic 32-08 was published as NCHRP Synthesis 327, "Cost-Effective Practices for Off-System and Local Interest Bridges". The document may be obtained at: http://www4.nationalacademies.org/trb/onlinepubs.nsf

An abstract is included as Appendix A.

Chapter 5

Summary and Conclusions

A description of the bridge design process, including both substructure and superstructure selection has been provided. In addition, other elements of the design process, namely geology, surveying, and hydraulics are discussed.

Design standard drawings available from KDOT are referenced.

Finally, reference is made to report K-TRAN: KU/KSU-03-3, "A Study of the Duties of a County Engineer in the State of Kansas." That report describes in detail the functions of a County Engineer. In that report, it is pointed out that Kansas statutes require an engineer to be licensed when making decisions involving the health, safety and welfare of the public. Further, the statutes require that every county employ a licensed engineer, whose title shall be "county engineer." However, many counties are not employing a county engineer.

A survey of road supervisors in Kansas counties (from the above report) indicated they want "access" to an engineer when they concluded that an engineer is needed to comply with the statutes. A self-test is provided for individuals to decide when conditions require an engineer's expertise.

A representative list of county engineering duties is included in that report, which indicates whether the function requires an engineer's license or may be performed by a non-engineer. This list is not all-inclusive, but it provides information for a non-engineer to decide if an engineer should be involved in the decision-making process. Some consulting engineers support the availability of engineering services in each Kansas county because they could provide the service.

5.1 Conclusions

Developing safe, adequate and cost-effective plans for low volume bridges requires a multi-disciplinary approach, including but not limited to the disciplines of surveying, hydraulics, structures, economics, environmental and geotechnical. The Kansas State Board of Technical Professions requires licensed professionals for bridge design and plan development. Use of KDOT standard drawings, or any other standard details, does not eliminate the need for a professional engineer to review and check the design plans for each specific bridge structure. The design professionals involved in plans development will meet the goals of providing safe, adequate and cost-effective structures.

These conclusions are supported by "A Study of the Duties of a County Engineer in the State of Kansas," Mulinazzi, Gumpa, and Russell, Sr., K-TRAN: KU/KSU-03-3, August 2005.

Legal issues including the Tort Claims Act have not been addressed in this report.

APPENDIX A

Cost Effective Practices for Off-System and Local Interest Bridges

NCHRP Synthesis 327 – 130 pages

(Originally 32-08 Cost Effective Structures for Off System Bridges)

Authors were from Iowa State University
Started-April 2001
Finished-June 2002
Published-November 2004

The report is considered an "owners manual," "users guide," or "toolbox" for bridges.

Off-system means <u>NOT the National Highway System</u>, and includes bridges on state roads.

The report was prepared from a literature review, vendors, and a project survey. 20 States (not including Kansas) and 70 local agencies (Kansas included---the responding agency(s) is not specified) from 10 states responded. (The answers tend to indicate the local respondents were local agencies with substantial resources (<u>not similar</u> to most Kansas counties)).

Generally, information is reported separately for states and local agencies.

NBI data was used to identify cities and counties own 54% of bridges nationwide (80% for Kansas on rural mostly low volume roads). 22% of capital funding went to local bridges (70+% to state and federal bridges). (In Kansas local capital funding was probably a little <u>lower</u> than the national average.)

Funding discussed is generally HBRRP (now HBP), STP, and Innovative federal programs, in partnership **with state and local funds**. The federal program allowing bridge maintenance was well received. Federal funding to fully fund preliminary engineering and bridge inspection was requested.

The need for repair and replacement of structures less than bridge length was identified as competing for funds, and therefore impacted insufficient funding.

Four funding alternative solutions were identified by Braumel et al. (1989) addressing the under-funding of an extensive network of roads:

- Large state and federal tax increases
- Local tax increase options
- Reduce road and bridge standards
- Abandon roads and bridges

When funding is just not available, Welte et al. (1997) reports closing roads, when properly done, is legal and does not carry liability.

Bridge and asset management tools are recommended (primarily a tool for states). These are generally based on life-cycle costing, asset preservation, and maximizing the impact of limited resources, not worst-first. **<u>Alternate strategies for rural states like Kansas are road abandonment or road closure</u>.**

Quality **engineering** through the traditional process **is assumed** in the report (this design process was mostly reported for federally funded projects so, this process is required). To expedite design and reduce design cost, use of standard drawings for structural considerations is recommended (locals are making use of state standard drawings). Consultants are the primary means of obtaining design services by locals. This reflects a lack of local in-house engineering capabilities or insufficient time for design when dealing with more pressing issues. A modified design standard for replacement low volume bridges is requested. This is to reduce costs for bringing "other" considerations up to modern standards. The *AASHTO Green Book* is the primary design guideline, (the **Low**

Volume supplement is available for local agencies). The Fed allows states to adopt different standards for local and low volume roads, but desires locals follow national standards. Locals view bridge and approach rails as prohibitively expensive or impractical ("too much railing") considering the character and volume of traffic. Appropriate waterway sizing (hydraulic considerations) is needed. Design aids available are intended to be used by engineers, not unlicensed administrative or maintenance personnel. A reduction of engineering personnel at the local level was cited as "challenges" to quality design.

Relaxed environmental and permitting processes are desired. Environmental and permitting is a substantial cost, and locals use a consultant, as they do not have staff with expertise. It was suggested that environmental agencies bear the cost of the environmental considerations they require. Prioritizing their funds may cause them to recognize that some impacts are significant and some are less, therefore, different standards may need to apply to different projects.

The concrete box culvert is identified as the structure of choice due to ease of design, ease of construction, relatively long life, and being relatively maintenance free. This is based on the use of standard drawings for structural considerations (locals are making use of state standard drawings). However, first cost is the most important criteria when selecting a structure.

Other structures have a similar installation percentage. See charts below for type of local structures built and local force construction endeavors. (This may reflect what agencies do, and not necessarily reflect quality of skills of local forces.) Pre-fabricated and pre-engineered bridges were generally not considered advantageous over site-built bridges. Raw data indicates locals consider pre-fabricated and pre-engineered bridges advantageous since locals have inadequate structural design staff. Topography and geology also impact type structure selected. Low water crossings replacing bridges were recommended where appropriate—*Low Water Stream Crossings: Design and Construction Recommendations* (Lohnes et al. 2001). A design manual is available. (Federal funds are not applicable to low water crossings.)

Regardless of type, structures built for locals were usually built by a contractor. Locals did not have personnel with bridge building skills. (This could be for a variety of reasons, possible pay scale.) However, where locals built their own bridges, it was more cost effective (possibly due to low local pay scale).

Repair, rehabilitation, and replacement options identified are those currently being used. Innovative county bridge departments recycle bridges or bridge components.

Sufficiency rating does not necessarily reflect the adequacy of the bridge, as a low sufficiency rating bridge may still service the traffic demands.

Results in this report are similar to NCHRP 222 and NCHRP 243 from 1980 and 1981. Despite identification a quarter century ago, deterioration and obsolescence are continuing to exceed maintenance and replacement.

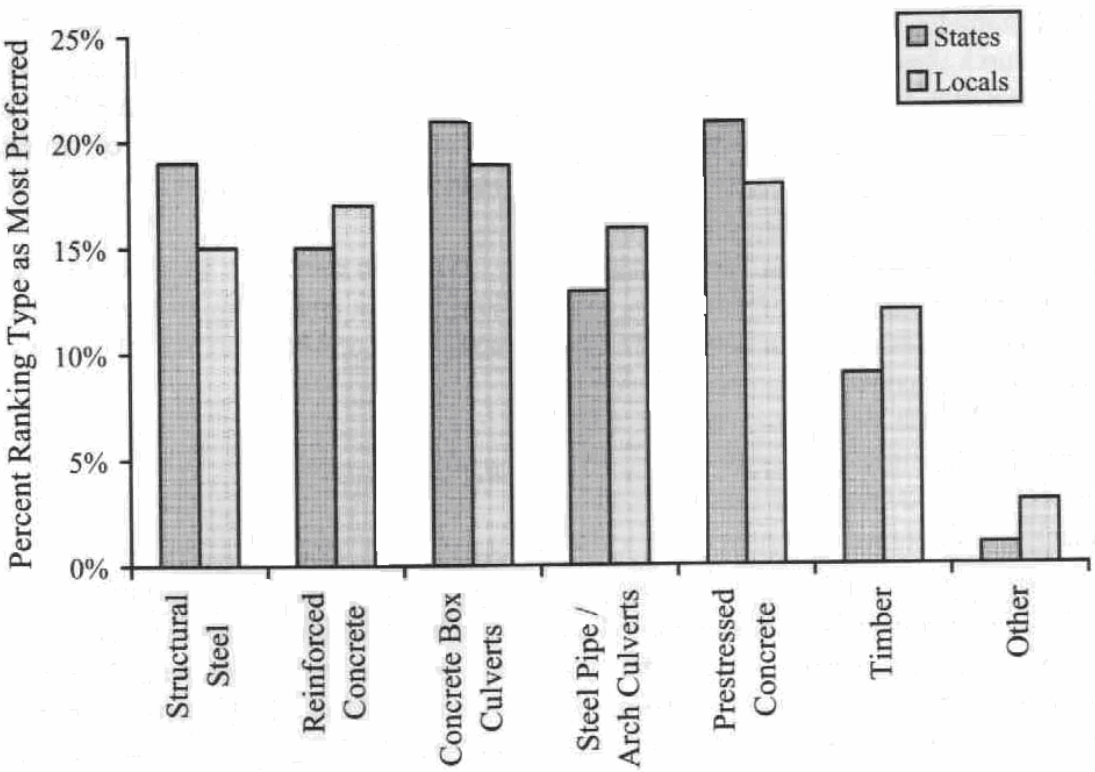

FIGURE 11 Structure type preferences from project survey.

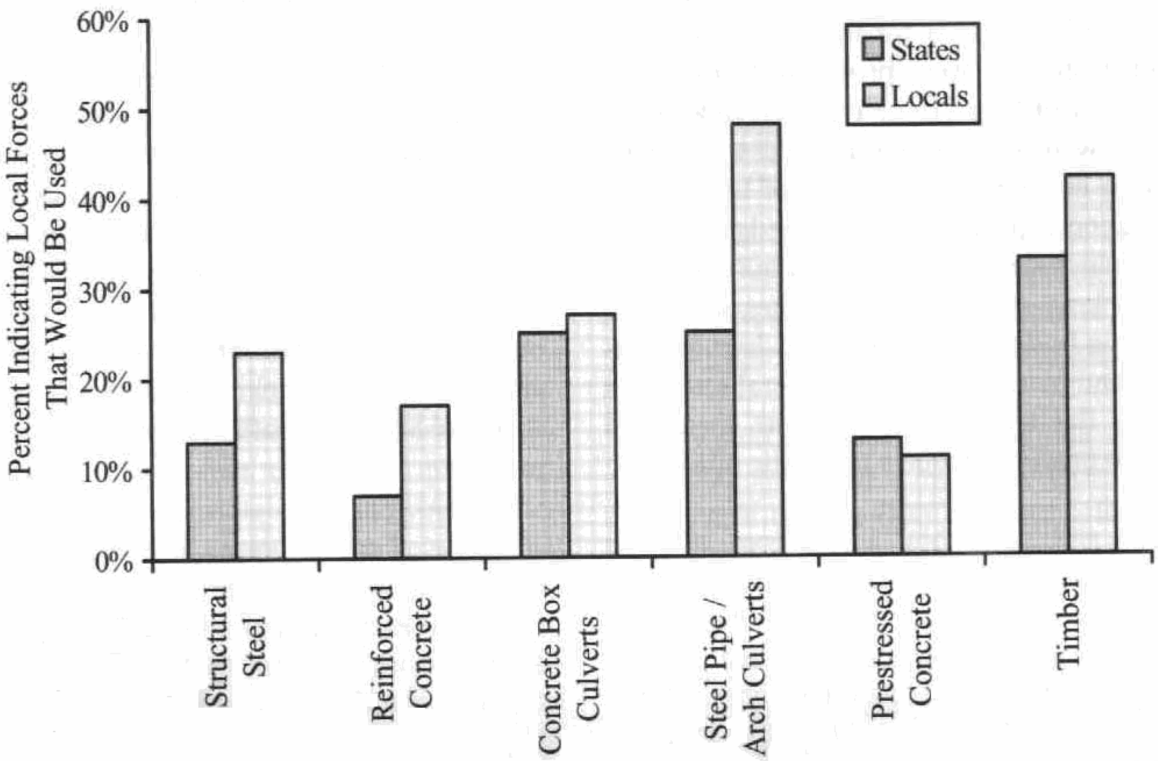

FIGURE 12 Construction capabilities of local forces.

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NCHRP Synthesis 327: "Cost-Effective Practices for Off-System and Local Interest Bridges"

K - TRAN

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AND
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A COOPERATIVE TRANSPORTATION RESEARCH PROGRAM BETWEEN:

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THE UNIVERSITY OF KANSAS

KANSAS STATE UNIVERSITY