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16. Abstract

The Advanced Highway Maintenance and Construction Technology Center has designed and build the next generation of a highly successful line of longitudinal crack sealing machines which Caltrans maintenance crews use statewide to maintain highway pavements. These machines have consistently produced dramatic cost savings combined with improved safety and seal quality. This new machine development focuses on further increasing seal production capabilities and worker safety. To accomplish this goal, the Transfer Tank Longitudinal Sealer (TTLS), would seek to create a continuous hot sealant supply for high production sealing operation by developing a hot sealant transfer from nurse kettles scheme. The TTLS system consists of two separate machines that were developed simultaneously. The application truck is a self-contained high production highway longitudinal crack sealing machine. The transfer trailer serves the role of nurse kettle by providing large amounts of hot sealant and high speed transfer capabilities to quickly re-supply the application truck. The development of both machines has been completed and initial highway testing of these machines has been conducted in conjunction with Caltrans maintenance crews. TTLS field testing results have proven the functionally of the equipment, but slow kettle heating times is ultimately preventing full deployment of this equipment. TTLS application truck kettle replacement will be necessary before field deployment can be accomplished.

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DEVELOPMENT OF THE TRANSFER TANK LONGITUDINAL SEALER

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Disclaimer Statement

The research reported herein was preformed as part of the Advanced Highway and Construction Technology (AHMCT) Research Center, within the Department of Mechanical and Aeronautical Engineering at the University of California, Davis and the Division of Research and Innovation at the California State Department of Transportation. It is a cooperative venture of local, state and federal governments and Universities.

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Abstract

The Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center has designed and built the next generation of Longitudinal Crack Sealing Machines (LCSM). At the time of this development, Caltrans had the second generation LCSM deployed in the Caltrans maintenance fleet and was producing cost savings combined with improved safety and seal quality. The increased seal production necessitated a similar increase in the supply of hot sealant to allow the sealing machine to operate continuously. This new system, the Transfer Tank Longitudinal Sealer (TTLS), creates a continuous hot sealant supply for high production sealing operations by developing a hot sealant transfer from nurse kettles scheme. The TTLS system consists of two separate machines that were developed simultaneously. The application truck is a self-contained, 360-gallon, high production highway longitudinal crack sealing machine. The transfer trailer serves the role of a nurse kettle by providing up to 600 gallons of hot sealant and high-speed, 72GPM (gallons per minute), transfer capabilities to quickly re-supply the application truck. The development of both machines has been completed and initial highway testing of these machines has been conducted in conjunction with Caltrans maintenance crews. TTLS field testing results have proven the functionality of the equipment, but slow kettle heating times of 7 to 9 hours is ultimately preventing full deployment of this equipment. The slow heating problem was due to poor kettle design by a commercial manufacturer. TTLS application truck kettle replacement will be necessary before field deployment can be accomplished.

EXECUTIVE SUMMARY

The goal of the Transfer Tank Longitudinal Sealer (TTLS) project was to develop the next generation machine in a line of the Longitudinal Crack Sealing Machines (LCSM) developed by the Advanced Highway Maintenance and Construction Technology Research Center (AHMCT) and the California Department of Transportation (Caltrans) Division of Equipment, deployed through Caltrans Division of Maintenance, and operated on California Highways. The new machine would both build on the successes of the previous LCSM machines and further extend system capabilities in order to realize the full potential of this type of equipment to decrease costs, increase production and improve the safety of crack sealing operations. The project deliverable was a fully functional high production crack sealing machine capable of being deployed through Caltrans Division of Maintenance for statewide operation. The intent of the new design was to mitigate several minor functional issues that surfaced with the existing equipment in the field, but would primarily focus on the development of a vastly increased hot sealant supply to meet the high production demand created when utilizing the LCSM. This new system, the Transfer Tank Longitudinal Sealer (TTLS) creates a continuous hot sealant supply for high production sealing operations by developing a hot sealant transfer from nurse kettles scheme. The TTLS system consists of two separate machines that were developed simultaneously. The application truck is a self-contained high production highway longitudinal crack sealing machine. The transfer trailer serves the role of a nurse kettle by providing large amounts of hot sealant and high speed transfer capabilities to quickly re-supply the application truck. Other machine advances include incorporating a sophisticated controller to mitigate operator training issues and total in-cab machine operator control to allow for moving lane closure highway sealing operations. The new machine prototype would also be developed in such a manner as to enable Caltrans to reproduce the machine through subcontract or through direct vendor purchase.


Longitudinal Sealing by Hand


TTLS Initial Testing in District 3

Fabrication of the two TTLS prototype machines was completed and the initial testing phase began in September 2005. Field testing of the TTLS system began with Caltrans District 3 maintenance crews on Highway 113 and later with District 4 maintenance crews on Highway 4. The application truck sealed for a relatively small trial period, but it was enough to verify the basic operation of the application truck and to generate evaluation feedback from the Caltrans maintenance crews involved. The majority of the longitudinal sealing was conducted in moving in-lane closures, which was one of the major goals of the TTLS project. Operating the application truck from inside the truck cab eliminated any direct worker traffic exposure on the highway and makes in-lane longitudinal sealing operations an altogether new cost effective option. Tests of the transfer trailer were also conducted off the highway in order to refill the application truck kettle. High-speed transfers took less than five minutes to complete the 360-gallon hot sealant transfer to refill the application truck kettle.

Field testing determined that the truck kettle required three to four times longer than normal to heat up to operating temperature. Since the most fundamental objective of the TTLS concept was to increase the hot sealant supply, a slow heating kettle proves to be a fatal flaw. The cause of the problem was determined to be manufacturer error and cannot be repaired. The protracted kettle heating time renders the application truck effectively useless for continued testing or any realistic form of field deployment duty. Besides the kettle, all other systems developed on the application truck are functional, and the machine is fully capable of conducting high-speed longitudinal sealing operations on the highway. The application truck contains many new features designed to optimize sealing performance and ease of operation, but these advances are being overshadowed by the deficient operational characteristics of the sealant kettle. Kettle replacement is the only viable option to enable the TTLS applicator truck to achieve field deployment status.

Background

LCSM

The first Longitudinal Crack Sealing Machine (LCSM) built by AHMCT consisted of a modified 350-gallon Bearcat sealant kettle trailer. The initial design did not have a dedicated truck to pull the trailer, but instead was designed to be quickly installed onto any available generic Caltrans stake side truck. To install the system, a simple applicator bar was clamped on the front bumper and a non-heated sealant hose was strung along the side of the truck to the applicator bar. For inside cab control of the applicator, a hand held controller and cable was snaked to the cab and in through an open window. The operator had only basic control of the applicator including raising and lowering the seal shoe and on/off control of the sealant. Sealant flow rate was set on the rear of the kettle with the position of the sealant bypass valve. In operation, the driver would slightly lean out the side window of the truck cab and steer the sealing shoe along the longitudinal crack while varying the forward speed of the truck to account for the variable width of the crack. As simple as this system was, it was very effective and quickly became the method of choice to seal longitudinal cracks in Caltrans Maintenance District 11.

LCSM in District 11

There were many advantages of using the LCSM over the standard hand operation. There was an obvious safety advantage by moving the workers applying sealant from the road to the safety of the truck cab. In most cases, the hand operation required at least two workers. One worker holding the sealing wand applying the sealant and a second worker to help manage the sealant hose. Some operations even had a third person to tool the sealant with a squeegee. The crew would relieve the person operating the sealant wand on a regular basis. The LCSM operation is not strenuous at all, the cumbersome sealant hose is not handled and the LCSM sealing shoe acts like a squeegee and produces an attractive and efficient tooled seal. So utilizing the LCSM could remove up to three workers from direct traffic exposure and reduce the overall manpower requirements for a typical longitudinal sealing operation to just one operator.

The continuous faster pace nature of the LCSM operation resulted in a dramatically increased seal production rate. In field operation, the LCSM typically operated at a continuous speed of 2-mph with speeds up to 5-mph easily obtainable. The lower operational speed was a result of sealant melting capacity concerns and not sealing shoe operational limitations. The increased sealant production rate was beyond the capability of standard sealant kettles to melt sealant, so it is difficult to quantify and compare the production rates to the standard hand sealing operation. Comparison was even more confused since LCSM sealing operations were taking place in lane closures at that time. A hand sealing operation would normally seal all cracks within the lane closure including traverse and any random cracking and not just the longitudinal cracks. This made a reasonable straight production comparison impossible. The simple observation that the amount of sealant applied in a day doubled when using the LCSM along with its safety advantages, enabled the LCSM machine to succeed in the field in the beginning. Years later Caltrans Maintenance crews using the LCSM2 were able to record production numbers that quantify the increased longitudinal seal production rate compared to a typical hand sealing operation (*see Appendix A*).

As the LCSM applied sealant, an equivalent amount of block sealant was fed into the kettle on the fly. All typical sealant kettles are designed to operate in this fashion. The LCSM kettle had a ramp and special loading hatches that provided a means for a worker to feed sealant blocks into the kettle from inside the truck stake side body while moving. The worker in the back of truck would remove the sealant blocks from their boxes and roll the blocks down the loading ramp into the kettle.

The initial use of a standard truck for the LCSM limited sealing operations to the driver side only. To seal the shoulder crack, the truck was driven in the opposite direction in the lane closure. Getting the truck turned around on the highway was cumbersome and often would require a CHP traffic break. To simplify right side operation, the LCSM system was installed on a dual steer truck supplied by Caltrans Equipment and modified to permit sealing operations off both sides of the truck. The dual steer modification also included an updated controller, which allowed for remote sealant flow control and a programmable logic controller (PLC) operator input panel inside the truck cab.

LCSM RESULTS

The LCSM was operated solely in District 11 on edge cracks for a year or two before being pulled out of service for modification into the LCSM2. During this time it was evident that two changes were required to improve the LCSM design. The first was the need for a heated sealant hose. The LCSM used a standard rubber sealant hose that could only be indirectly heated in a kettle mounted hot box. This type of hose is notorious for having cold spot plugs that prevented hot sealant from flowing through. Properly heating the sealant hose often lead to long delays and on cold and windy days, the hot sealant may not be made to flow through the application hose all day. At this time, heated sealant hoses were just being introduced on production melters and future modifications to the LCSM would certainly benefit from this technology.

LCSM Trailer

The most critical improvement at hand was to dramatically increase the supply of hot sealant available for application. The LCSM at this stage could apply all the hot sealant in the 350-gallon kettle in a little over an hour of sealing at a 1-1/2 to 2-mph pace. Since sealant blocks were added as the sealant was being applied, the sealant mass temperature dropped, but most of the 350-gallons of liquid sealant was applied. With all the hot sealant removed from the kettle, recovering the full 350 gallons of hot sealant could take several hours. The speed of application was slowed down to about 1-mph in an effort to get the most use of the hot sealant mass before it was applied. The larger the hot sealant mass in the kettle the quicker the replacement sealant blocks would melt. Once the hot sealant mass was gone the remaining sealant blocks were not in contact with the internal heating surfaces in the kettle and the melting process slowed. Even when slowing down the sealing operation, at best, half of the time on the highway was spent waiting for the kettle to recover. Doubling the days seal production while only working half as long was tremendously popular with the maintenance crews, but clearly, a new approach had to be developed to drastically increase the hot sealant supply.

AHMCT made an attempt on the LCSM to increase the melting speed of the replacement sealant blocks by slicing them into smaller pieces. The theory was that the smaller slices of sealant block would have a larger surface area and therefore would melt quicker. A heated knife grate was developed and installed over each of the two sealant block loading openings in the top of the LCSM kettle. Sealant blocks placed on the heated grate would take a long time to melt through. So to speed the process, the blocks would have to be forced through the slicing grate. Devices called dog houses were developed to replace the standard loading hatches. Originally the dog houses were designed only to enable the remote loading of sealant. Blocks were slid down the loading ramp from the back of the truck and would force open a swinging door on the dog house and fall into the kettle. The two dog houses were redesigned to incorporate a hydraulic ram plate mechanism capable of forcing sealant blocks through the heated grate. The new dog hoses with the ram plates could extrude up to three blocks at a time through the heated grate in a minute or two. The block shredder was installed on the LCSM kettle trailer and tested briefly in District 11 on the highway. The shredder worked as planned melting the blocks much quicker, but the sealant mass temperature dropped as well. The kettle heating surfaces were not capable of transferring the additional heat to the sealant mass to account for the increased block melting capacity. Consequently the heat was obtained from the sealant mass further dropping its temperature. The old problem was that the kettle contained unmelted blocks and very little liquid sealant, the new result was a colder semi liquid mass without blocks. Either

LCSM Loading Ramp

way the sealing process had to be halted until a sufficient mass of hot sealant could be reestablished.

Even though Sealant block shredding did not directly solve the high volume sealant melting problem, it removed one of the major hurtles. If shredding was combined with an equal improvement of the heat transfer capability of the melter, the problem could potentially be solved. There are two basic methods of improving heat transfer. First the temperature gradient can be increased and second the heat transfer surface area can be increased. Since the sealant properties prohibit a greater temperature gradient, increasing heating surface is the only feasible alterative. Kettle manufactures have been experimenting with different kettle designs for decades and all designs utilize indirect heating with heat transfer oil. Two schemes have emerged to transfer heat from the hot oil to the sealant mass. The most common method surrounds the bottom and sides of the sealant vat with a hot oil jacket. The LCSM kettle utilized the alternative method of containing the hot oil in coiled tubes and plumbing inside the sealant vat. Both designs have roughly the same heat transfer surface and consequently similar sealant heating capabilities. For the typical hand crack sealing operation these kettles are sufficient, but because of the high production rate of the LCSM, standard kettle designs proved to be inadequate. It was clear that if sealant heating capability was to be drastically increased, a custom kettle would have to be developed.

LCSM2

The primary goal of the development of a second generation longitudinal crack sealing machine (LCSM2) was to mitigate the hot sealant supply shortage issue. A simple line of reasoning emerged that guided the redesign effort. Since in general terms the existing LCSM spends half of the time on the highway idle waiting for the kettle to recover, doubling the number of kettles used in the operation should provide for nearly continuous operation. The operational concept of the new machine would remain the same as the original sealing machine, the major difference would be that two kettles would be used instead of one. Doubling the size of a single kettle may have had the same effect, with half as much hardware, but since Caltrans already had two kettles and a large trailer on hand, the double kettle approach was undeniable. The LCSM that was successfully deployed and in operation in District 11 was removed from service so the dual steer truck and kettle could be modified into the LCSM2.

LCSM2 Double Trailer

Operating the two kettle trailers independently in a longitudinal sealing operation on the highway was not practical. Hand sealing operations have occasionally operated two kettles on the highway at once, but this approach conflicts with the continuous nature the LCSM operation and the additional complication of an elaborate truck/trailer connection. The LCSM2 would use a double kettle trailer for twice the sealant capacity while maintaining all the advantages of operating a single trailer. The double kettle trailer was custom built and consisted of the 350-gallon Bearcat melter from the LCSM and a 200-gallon Bearcat from Caltrans fleet. Both were stripped off of their trailers and attached to a larger heavy-duty trailer. The kettles were mounted sideways to allow for access to all four loading hatches from a single block loading ramp and to simplify plumbing connections.

The loading ramp was an important feature employed on the LCSM to allow for remote sealant block loading while moving. In a high sealing production mode, blocks would pileup in the kettle under the loading hatches clogging the openings. To minimize clogging, it was essential that the introduction of sealant blocks be evenly distributed to all available kettle openings. Since the LCSM2 would operate the same way, a loading ramp that could load all four loading hatch openings had to be developed. A horizontal ramp with powered rollers was mounted on the trailer with one end extending slightly into the back of the truck body. The other end of the ramp ended at each of the loading hatches in a stepped fashion creating a path to each of the four openings. A sealant block was sent to a certain opening depending on which of the four parallel belts it was placed on the truck end of the ramp. Hatch covers were developed with flapper lids that allowed for the dropped sealant block to push open the flapper and fall into the kettle. The ramp was set high enough over the openings to create a sufficient dropping inertia to reliably open the flapped hatch cover.

LCSM2 in District

A single trailer mounted diesel engine powered both kettles supplying the necessary hydraulic and electrical power. The two kettles were mounted and modified on the common trailer such that either kettle could supply the truck, or the kettles could pump to each other. Both kettles retained their individual operation abilities with standard hand hydraulic valves and automatic diesel burner controls. The identical PLC control first employed on the LCSM was also utilized on the LCSM2 which provided programmable logic control capabilities to the machine. The PLC simplified the user controls and on the LCSM2 was additionally used to select which kettle output would flow to the truck from inside the cab.

The sealant passage on the trailer flows from the kettle to hitch area. At the hitch, a quick connect sealant line connection provides a means of quickly decoupling the trailer from the truck. A second sealant passage runs from the hitch area forward to the applicator bar on the front bumper of the truck. The sealant passages on the trailer have always been hot oil heated, but the passage on the truck half was not heated on the LCSM. The LCSM2 incorporated an electrically heated sealant passage in the truck that greatly simplified the startup process eliminating the unpredictable, time-consuming task of developing hot sealant flow.

LCSM2 RESULTS

Following a brief highway testing period in District 3, the LCSM2 was placed in general service in March of 2000. Initially the Caltrans Maintenance crews operated the new machine with the same procedure as was developed for the LCSM. The LCSM2 was initially deployed in District 11 because of their extensive experience with the first machine. Since it took over three years to rebuild the machine, the original crew that operated the LCSM throughout District 11 were no longer available to operate the LCSM2. This made a comparison between the production rates of the two machines difficult to quantify and no comparison is know to exist. The LCSM2 gained quick acceptance in District 11 and became the method of choice for longitudinal sealing operations district wide (*see Appendix A*). Soon the LCSM2 was brought up to District 6 and used to complete a longitudinal sealing job in the Fresno area. It was in District 6 when the practice of allowing Caltrans Maintenance workers ride in the back of the moving truck was rejected based on safety concerns. Removing the rear tailgate on the LCSM2 to provide access to the new lower ramp design presented an obvious safety hazard that most likely instigated the Caltrans safety decision. The argument had always been that a worker riding in the back of a slowly moving truck body is safer than direct traffic exposure on the highway. This argument was not able to reverse the Caltrans safety decision because a traffic hit on the kettle trailer could spray 400 degree hot sealant over the contents of the truck body. Since the LCSM2 was based on the introduction of sealant blocks as the sealant was applied, the production rate of the machine was greatly reduced. The LCSM2 operation became simply limited to emptying the contents of both kettles. Recovering an empty kettle typically takes overnight when considering the short Caltrans traffic work zone window. Likewise, the continuous nature of the LCSM2 operation makes the process of routine stopping for loading undesirable.

Kettle Hit Picture in District 10

The Caltrans Maintenance crew in District 6 developed a new LCSM2 operational procedure to extend seal distance with the now limited two kettle contents limitation.
After the double kettle trailer was emptied on the highway, the crew had a third hot kettle waiting off the highway in reserve. This standard issue kettle was then towed out on the highway and the hot sealant was then pumped into one of the double trailer tanks. This approach increased the two kettle capacity to three and thereby extended the highway sealing distance of the LCSM2. This hot sealant transfer approach fit into Caltrans safety procedures and eliminated the problem of wait times on the highway as the kettles were recovered with block sealant. Since standard kettles are designed for hand application, the

transfer was slow and the amount of sealant small, but the method was working nevertheless. If the transfer speed and sealant capacity could be increased, an obvious benefit from this method could be realized. The success of this procedure would go on to form the conceptual basis of the next generation LCSM.

The LCSM2 was typically driven along the shoulder of the highway sealing the edge cracks. Increasingly these operations had Caltrans Maintenance crews sealing these edge cracks without closing traffic lanes when the shoulders were wide enough. The advantages of not establishing lane closures for crack sealing operations are numerous and unique to a LCSM operation. Establishing a lane closure requires a fair amount of time and labor and restricts traffic flow. Savings realized by reducing the necessity for fixed lane closures can be quite significant. A cost analysis was conducted in District 11 comparing LCSM2 operation to the traditional hand sealing operation (see appendix A). These dramatic cost saving totals of LCSM2 operation are influenced heavily by the new no lane closure practice. The higher production rate of the LCSM2 is further enhanced with non lane closure operations by lengthening the time available out on the highway sealing. A working window of time on the highway exists after the morning rush hour and before the afternoon traffic begins again in most areas. Establishing a lane closure reduces the size of the sealing window on both sides by hours.

LCSM2 in District

In 2004 the LCSM2 trailer suffered mechanical problems and was removed from service. The primary problem was related to the failure of the 200-gallon Bearcat kettle on the dual kettle trailer. The Caltrans Equipment shop investigated the possibility of outside sources making the needed repairs and requested cost estimates. The repair costs came back quite high and together with the looming availability of the next generation LCSM, repairs were placed on hold. In May 2005 the Caltrans Equipment Division had scrapped the LCSM2, removed all LCSM2 components from the truck and salvaged the trailer.

NEXT GENERATION LCSM ISSUES

Soon after the Caltrans Safety decision came down to restrict workers from the back of the LCSM2 while moving, an interest in the development of a new LCSM design began to emerge. This no riders decision nullified a key component to the LCSM operational strategy. All standard sealant kettle manufactures have a fundamental requirement that their kettles be kept at least nearly full, therefore, sealant blocks have to be replaced as the hot sealant is removed. This ensures the internal heating surfaces remain covered and the hot sealant mass aids in the melting of introduced sealant blocks. When a kettle is run nearly empty, the exposed internal heating surface burns the thin coating of sealant creating an insulating cover diminishing heating capabilities. Likewise the lack of a hot sealant mass dramatically increases the melt time of sealant blocks by hours and up to days in some cases. While loading blocks in a typical operation is not much of a problem, the continuous high production nature of the LCSM complicates this task immensely. Since the LCSM project relied heavily on riders to keep the kettles full while moving, clearly an altogether different scheme would have to be developed to fit into Caltrans safety procedures. The clue to a possible solution was found in the District 6 operation that had used the nurse kettle. The exact procedure this crew was using with equipment on hand did not produce a large increase in seal production alone, but the overall concept did offer great solutions to many problems that have been lingering around the LCSM program for some time.

One of these problems had been the sealant application temperature. Sealant manufactures recommend an application temperature for their climate sensitive products. In the effort to melt sealant at an increasingly quicker rate, no attention was being paid to, nor effort made to control the application temperature of the sealant. Sealant becomes liquid at temperatures far below recommended pour temperatures. The research into increasing hot sealant supply on the highway was simply focusing on the quick melting of sealant blocks to liquid so it could be pumped out. This alone was a challenge that was not able to meet given the high production rates the LCSM was able to accomplish. The additional time required to bring the liquid sealant also up to recommended pour temperature would have the effect of dramatically slowing down the overall seal production rate. Nonetheless, since the majority of the cost associated with crack sealing is related to application and not the cost of the material itself, applying the sealant at the recommended temperature to attain maximum seal life is tremendously cost effective. The maximum temperature the sealant mass can be maintained is very close to the pour temperature, so any accelerated scheme to introduce cold blocks would enviably draw down the sealant mass and pour temperature. The easiest solution to this problem is not to introduce sealant blocks while applying sealant which consequently was the effect of the Caltrans no rider rule.

In its simplest form the District 6 nurse kettle operation was different in that it brought the sealant supply out to the highway hot and ready to use, not cold and in boxes. Once hot sealant was transferred to the LCSM2 from the nurse kettle, it was ready to be applied to the pavement. This approach solves the many problems associated with having to melt sealant out on the highway while moving such as riders and low pour temperatures. The nurse kettle was loaded and heated off the highway, mostly in the Caltrans maintenance yard and was brought out to the LCSM2 for transfer when needed. This scheme in essence decouples sealant application from the resources required to heat large quantities of sealant, enough to supply a high production sealing operation. Imagine several nurse kettles with high speed transfer abilities supplying the LCSM, the machine would have a virtually continuous supply of hot sealant available and production would increase. This model formed the basis for the development of the next generation of LCSM.

CALTRANS INPUT ON THE NEW LCSM DESIGN

The limited hot sealant supply that the LCSM2 was capable of providing was typically the restricting factor to daily seal production rates. Further expanding the sealant melting capability for the new machine was the most essential improvement. When Caltrans maintenance crews using the LCSM2 experienced the hot sealant limitation, they would usually seek ways to extend the machine's seal production abilities. This combined with the Caltrans safety restriction on workers in the back of a moving truck had prompted the LCSM2 crews to improvise operational solutions. The transfer of hot sealant was one of these improvised procedures developed in the field by Caltrans maintenance crews. This transfer procedure was later developed into a new machine concept that would have a larger tank capacity and a means for high speed sealant transfer. The now called transfer tank concept offered the potential of dramatically increasing the hot sealant supply and improving LCSM seal production capabilities.

The new transfer tank concept was presented to maintenance crew personnel in Districts 6 and 11, both which had first hand experience operating the LCSM2 in successful highway sealing operations. Both crews approved of the transfer concept and provided information that would ultimately lead to major specification changes in the next generation LCSM design. Since some of the crews already had some experience with the technique, presentation and acceptance of the transfer concept was relatively straightforward. One of the first changes made as per Caltrans input was in the size of the application truck.

LCSM2 Cab-over

The initial concept for the next generation LCSM created by AHMCT had intended to use the largest available sealant tank on the applicator truck to achieve maximum production capacity. The initial concept presented suggested the use of a large truck mounted tank in the thousand-gallon range. The extreme load weight this represented required a large heavy-duty chassis. Caltrans Maintenance preferred that the applicator truck focus on light maneuverability for getting into and out of work zones on the highway. Improving maneuverability would result in a trade-off with a much smaller truck tank capacity. The Maintenance crews agreed that a truck's maneuverability warranted the trade-off of a smaller truck tank that would require more transfers.

The dual steer truck generously donated by Caltrans Equipment was a heavy duty Cab-over style Volvo. Other than a problem with driver ergonomics, this was an ideal platform for the LCSM and LCSM2. When sealing cracks, the driver leans partially out the side window to be able to directly view the sealing shoe while still maintaining an unobstructed view ahead in the lane. The side windows of the Volvo cab did not go all the way down into the door and the glass that stuck out made the driver very uncomfortable especially over long distances. Some operators used a foam cushion and still others used padded sleeves, but nothing seemed to solve the problem. The driver in the cab-over style cab also sat up very high which made looking down at the sealant shoe while sealing cracks uncomfortable. Caltrans Maintenance crews requested that the new longitudinal machine not use a cab-over style cab and would be chosen for optimum driver ergonomics when sealing.

Machine operational training was a major issue with the LCSM2. The Caltrans crews that operated the LCSM2 were initially trained on the use of the machine, but as it was moved around to new areas the training became passed along by word of mouth. The later crews that used the LCSM2 had only basic knowledge of the machine passed along and were developing operational procedures based on cause and effect. The crews were asked if better documentation or an instructional video would solve the problem. The response was that these methods have been around for a long time, but in practice detailed instructions are not read completely and a video too time consuming generally leads to a loss of attention. The crews prefer a machine that its operation is intuitive and obvious and if a few operational instructions are required that they be straight forward.

The LCSM and LCSM2 had the ability to control the sealant flow to the sealing shoe by the operator from inside the truck cab. The crews that operated the LCSM2 noticed that the sealant flow with the control wide open was slower than desired. One possible explanation for this was that the size of the heated sealant passages were smaller than the LCSM which used the same pump and an equally long sealant hose and passage. The new machine would be designed with oversized sealant passages to ensure adequate sealant flow to the sealing shoe would be possible.

Caltrans Division of Equipment requested that the new LCSM use environmentally conscious fuels often referred to as green to enable the machine to be operated in areas of the state with increased air quality standards. The previous LCSMs relied on diesel to fuel the truck engine, auxiliary power engine and the kettle burner. The goal was to operate the new LCSM design solely on clean propane fuel. The C-Series GMC truck was not yet available with an engine capable of running on propane fuel, so a gasoline engine was purchased as the second best option. It was requested that diesel fuel had to be avoided for air quality restriction reasons. Except for the truck, the remaining engines and burners would all be operated on propane fuel.

Caltrans Division of Equipment also requested that the new LCSM be developed in such a way that Caltrans could reproduce more machines if needed. Previous LCSM prototypes were built internally which works for research projects, but any future building of copies does not fit into research resources. Past efforts in developing reproducibility resources through commercialization have been slow in development and problematic relating to purchasing issues. The development effort of the new machine would include an effort to develop new resources to mitigate machine reproducibility problems.

MAXIMIZING BENEFITS FOR THE NEW LCSM DESIGN

The ultimate goal of the development of the LCSM program has always been the design of a machine capable of moving lane closure operation. This feature has several major benefits and produces dramatic cost savings. By not establishing lane closures traffic congestion is reduced, operational time on the highway is increased within the traffic window, and cracks in areas where fixed work zones are not practical can be sealed. The labor costs for establishing fixed lane closures is a large part of the cost of a crack sealing operation. By reducing or eliminating the need to establish fixed lane closures, generous cost savings can be realized. In addition, not requiring a crew to go out on the highway to establish a fixed lane closure, worker exposure is reduced providing a safety benefit as well. To maximize these benefits, new features would be incorporated into the new machine design that would further develop the abilities to conduct longitudinal crack sealing operations on the highway in moving lane closures.

Hand Operation Sealing All Cracks

Moving lane closure operation in a live traffic lane is a new concept, but conducting longitudinal sealing operations along the shoulder next to live traffic lanes was a common practice with the LCSM2. Caltrans maintenance crews would drive the LCSM2 along the shoulder and seal the shoulder crack on both sides of the highway. This type of operation resulted in the dramatic cost saving compared to the typical hand longitudinal crack sealing operation (see Appendix A). The new LCSM machine design would focus on the development of a machine capable of sealing longitudinal cracks between lanes in a moving lane closure.

The most fundamental feature the new LCSM must contain to make moving lane closure operation possible is the ability to seal cracks without ever having to step out onto the highway. The operator/driver must have complete control over the sealing machine from inside the truck cab. The speed of the truck when sealing longitudinal cracks should ideally average approximately 5-mph even if for only short periods of time. Another advantage of a moving lane closure is that it has a minimal impact on traffic and can removed from the highway immediately should traffic begin to back-up due to the sealing operation.

Intangible benefits with dramatic cost saving are created when the ability to seal longitudinal cracks between lanes without lane closures is developed. Traffic considerations limit the use of lane closures on major highways. Caltrans maintenance restricts the use of lane closures to only the most essential maintenance tasks. Sealing longitudinal cracks between lanes is a lower priority and unless they present a traffic hazard, they are rarely sealed. The TTLS would make it possible to seal these longitudinal cracks between lanes that are currently going unsealed. Sealing these cracks extends the interval between major highway renovation which generates major cost saving benefits. If a lane closure is to be established, then it is advantageous to seal all the cracks in the closed lane including the random cracks and transverse joints. In this case the LCSM can still be useful by sealing the between lane longitudinal crack ahead of a hand operation which is sealing the remaining cracks. This approach can be implemented to shorten the closure time for a given section of highway, or can be used to dramatically extend a days production by relieving the hand crew of the responsibility of sealing the longitudinal crack as they go.

THE TTLS SEALANT CONCEPT

The ability to heat a sufficient quantity of hot sealant to match the high production capabilities of the LCSM has always been the limiting factor to the machines effectiveness. The concept for the next generation LCSM would attempt to mitigate this problem by developing a radically new operational concept centered on sealant supply transfer. Since the new machines operation would be radically different than the LCSM, the name LCSM3 would not be used. Instead, since the new operational concept centered on the transfer of hot sealant, the new machine was called the Transfer Tank Longitudinal Sealer (TTLS). The primary goal of the TTLS was to test the success of a transfer scheme to provide a virtually continuous hot sealant supply. Upon further study though, the transfer concept provided the opportunity to mitigate other problems experienced with the LCSM as well as several new features that could be included to further improve the safety, operation and cost effectiveness of the new machine.

It was this need to obtain a considerably greater supply of hot sealant, which led to the adoption of the transfer tank concept. At first glance, the transfer concept may appear to be more complicated than just attempting to accelerate the current method. The history of the LCSM project describes in detail several attempts to accelerate the melting process, which have never led to a solution. Along with the operational reasons, it is the characteristics of the polymer-modified sealant itself, which resist all fast melting techniques. The fact that this sealant has the heat conduction properties of an insulator and burns into a permanent solid state if in contact with a surface at a temperature much above its pour temperature makes the sealant by definition a material slow to heat-up. Only by surrendering to this fact can one begin to see the simplicity of the transfer process. The transfer process lets the sealant heat-up at its natural rate avoiding the whole range of problems encountered in the many attempts to accelerate the process. The accelerated melting process is like a serial process forcing more through one system, while the transfer process is like a parallel process where additional systems are employed at the normal flow to increase the output. Given a system operating near its capacity, it will always be the parallel process, which will provide the greatest output potential.

While it is true that the additional kettles would be required for the transfer scheme, the kettles used are standard kettles that the workers are familiar with. Assuming a single accelerated kettle was possible, this kettle would have additional hardware and a more complex operational procedure to be dealt with, which would most likely be a wash. Overall no mater what the details of the operation, the transfer system will always require far less labor and time as a standard hand operation and in most cases far less. There is a seemingly endless variety of ways that multiple kettles can be operated in a transfer sealing operation, which would allow the tailoring of the operation to a wide range of local circumstances. Multiple kettle operations can also be easily scaled up or down depending on the requirements of a specific job, by simply changing the number of kettles used. By decoupling the melting of replacement sealant from application, the bulk of the overall process is off the highway, thereby, reducing the work zone presence and worker exposure.

The transfer approach can be thought of in simple terms as a method of bringing the additional sealant out to the highway work zone hot, liquid and ready to use. This would obviously extend seal production. Standard kettles could be used for this purpose, but the process would be considerably improved if the sealant transfer speed were greatly increased. In addition if the size of the transfer kettle were significantly larger than the tank on the application truck, the remaining hot sealant mass could speed the recovery of the transfer kettle. Primarily for these two reasons a special use transfer kettle was developed for the TTLS project. Standard kettles could still be added to the operation further extending production, but the transfer tank alone should have a sufficient capacity for most Caltrans sealing operations.

FIELD-MIX SEALANT

Field mixing is another concept that could have been used to create an abundant hot sealant supply. Hot applied polymer modified sealants are a mixture of mostly petroleum sludge and smaller amounts of crumb rubber. The rubber is mixed with the hot petroleum oil and after some simmering time is poured into boxes to cool. The boxes are easily handled and stored, but must be reheated to be applied. Since the sealant has the thermodynamic properties of an insulator and easily burns when exposed to high temperature gradients, reheating is a slow process. Field mix is a concept that eliminates the reheat process altogether. A heated tank of petroleum sludge can be readily purchased throughout California and delivered in a thousand gallon insulated tank. The hot petroleum is pumped through a special built machine that mixes in the crumb rubber from a hopper at a preset ratio and discharges into the application truck kettle. Originally these types of sealants were all field mixed, before the industry switched to boxed sealants.

The TTLS concept was selected for development over the field mix method primarily because it was more similar to the current process and therefore, could achieve quicker acceptance in the field. Caltrans maintenance has an established approval and procurement system in place for boxed sealants. Field mix equipment and sealants would have to take the extra step of gaining approval for widespread Caltrans use. To speed the deployment process and get new sealing equipment into the hands of Caltrans maintenance, boxed sealant would be the material of choice for this project. Since field mix offers many advantageous benefits over boxed sealants, future research efforts may include the further development of this concept.

EMBRACING TECHNOLOGY

The LCSM2 represents presumably the most technically advanced crack sealing systems to ever be deployed on the highway for general operation. Even though great effort was taken to minimize the technological complexity of the LCSM2, the operational process required a certain level of technological complexity just to operate the many on-board systems which must be controlled in concert for the machine to accomplish its function. The success of the LCSM proved that complex technologies could reliably function in the harsh highway environment and that the standard maintenance worker could utilize complex technologies to improve and simplify a maintenance task. Using an advanced controller on the LCSM2 actually reduced the overall system complexity and implicitly improved system reliability.

Instead of minimizing the use of advanced technologies, the objective of the TTLS design was to maximize the use and benefit of technology. Since the TTLS was destined to contain some form of digital controller, it is therefore beneficial to choose an advanced controller with features that fully realize machine capabilities. TTLS sub-systems were designed to take full advantage of and provide useful information to, the advanced controller. The design goal was to develop a machine which is simple to operate and maintain by fully integrating a user interactive controller to the machine hardware. The ultimate goal in this process is to use technology to achieve fully automated operation, which would require little if any specific operator training. The controller would also contain self-diagnostics which could identify failures and instruct the operator how to make simple repairs, like resetting fuses.

TTLS System Descriptions

TTLS BASIC SYSTEM DESCRIPTION

The TTLS system physically consists of three distinct parts: applicator truck, transfer trailer and trailer propane tanks. Since the trailer propane tanks are the external fuel source only for the transfer trailer, in general terms the TTLS system can be thought of consisting of only two parts. The TTLS truck is the most important half of the system, because it can be operated alone as a fully functional crack sealing machine. The transfer trailer only plays a supporting role providing a transferable hot sealant supply for the application truck. For smaller crack sealing jobs requiring less than 360-gallons of sealant a day, the applicator truck can be operated alone without the transfer trailer. For larger crack sealing jobs requiring more than 360-gallons a day, the transfer trailer would typically be operated in tandem. With the truck tank sealant exhausted on the highway, the trailer could provide enough hot sealant to completely refill the truck tank thereby doubling the application truck's longitudinal crack sealing production capabilities. The size of the trailer tank is much larger than that of the truck tank, so that after the transfer a large mass of hot sealant remains in the trailer to accelerate sealant recovery. Ideally, the trailer will be able to recover in time to make additional transfers to the truck tank as necessary. This scheme in principle could be able to provide a virtually continuous hot sealant supply.

TTLS TRUCK BASIC DESCRIPTION

The TTLS application truck is a fully self-contained longitudinal sealing machine capable of heating and applying hot applied polymer modified sealants on the highway. The truck chassis has dual steering, controls and indicators to enable the driver/operator to conduct longitudinal sealing operations off either side of the vehicle with a minimal configuration change. A single operator/driver can control the entire machine from inside the truck cab without having to step out onto the highway. A multi colored touch screen user panel inside the cab provides for control and monitoring of all components necessary to operate the sealer. The system is Programmable Logic Controller (PLC) controlled with a user program that automates machine set-up and simplifies operation. The TTLS truck carries a 400-gallon hot applied crack sealant kettle with a single propane burner. The tank is mounted to the truck with a load-sensing mount that allows the sealant level to be monitored on the user panel. A 25-

TTLS Application Truck

horsepower auxiliary engine mounted on the rear of the truck body powers both the truck hydraulic system and the 24Vdc electric system. The truck system utilizes propane fuel for the kettle burner and gasoline for both engines.

In operation, the TTLS truck kettle would typically be heated up off the highway and filled with sealant blocks. The truck kettle can also be filled with hot sealant from the trailer transfer tank. After the kettle is filled and has reached operating temperature, the truck would then be driven out onto the highway to conduct longitudinal sealing operations. The kettle is automatically configured for hot transport to the work zone. The propane burners are switched off and generator powered electric heaters maintain operating temperature while traveling on the road. The applicator bar would be unfolded into sealing position immediately before entering the work zone. Upon entering the work zone the system is automatically returned to normal operation and the propane burners reengaged. The driver/operator positions the truck in the lane such that the sealing shoe is centered on the longitudinal crack. The shoe is lowered to the pavement surface and the sealant flow is engaged by pushing a button on a wireless remote control held by the driver/operator. Sealant fills the sealing shoe and then the truck is then driven along guiding the sealing shoe centered on the longitudinal crack by steering. The speed the truck is driven along the crack depends on crack size and sealant flow which can also be varied by pushing buttons on the wireless remote. Subsequent button presses on the remote stops the sealant and again lifts the sealing shoe.

TTLS TRANSFER TRAILER BASIC DESCRIPTION

The TTLS transfer trailer serves only one purpose, to provide a supply of hot sealant to refill the TTLS truck tank. The trailer does not have a sealing hose, or wand attached that can be used to directly seal cracks. Instead, the trailer only has a transfer hose designed to transfer its load of hot sealant to refill the truck tank quickly and safely. The transfer trailer is a fully self-contained large capacity hot applied sealant melt and transfer system consisting primarily of a 600-gallon sealant kettle. The considerably larger size of the trailer kettle compared to that of the truck is to boost sealant melting recovery time. The kettle is attached to the trailer with load sensing mounts so the sealant level in the kettle can be accurately monitored by the PLC. The TTLS transfer trailer runs completely on propane fuel that is supplied by dual external cylinders. The trailer kettle is loaded manually with standard sealant blocks through two non-splash hatches. The trailer kettle has a low profile design to provide for easy block loading from the ground. The entire

TTLS Transfer Trailer

operation of the transfer trailer is controlled by a PLC mounted in a steel enclosure on the trailer through a user panel.

In operation, if a job will require more than the 400 gallons of sealant that is in the TTLS truck tank, the TTLS transfer trailer should be heated and filled at the same time as the truck. So when the TTLS truck tank is depleted, the transfer trailer is ready to transfer the hot sealant to refill the truck tank. The hot sealant transfer can take place back in the maintenance yard, or for more remote job locations, the TTLS trailer can be towed out to a safe place near the job site for the transfer. Following the transfer, the trailer tank would be refilled with sealant blocks with the remaining hot sealant speeding kettle recovery. Ideally, the trailer kettle would be able to recover in time to make additional transfers to the TTLS truck as necessary. These subsequent transfers may take place at a lower temperature than the first transfer that would typically be up near recommended sealant application temperature.

Since the TTLS trailer vat is much larger than the truck vat, the potential for overfilling is problematic. To mitigate this issue, the transfer process is managed automatically by the PLC with the operator only having control over the initiation and termination of the process. A safe transfer of hot sealant involves the coordination and monitoring of many systems and parameters that are best managed by a fail safe program. The operator runs the sealant transfer process from the user panel on the transfer trailer. The operator is prompted to heat the transfer hose, connect to the truck and initiate the transfer process. The TTLS truck is passive in the transfer process with the sole task of constantly sending its sealant tank level via a wireless signal to a wireless receiver on the trailer. The transfer trailer pumps sealant to the truck vat only if a valid sealant level signal is being received from the truck and stops automatically when the truck vat is full.

TTLS REPRODUCIBILITY

A new development process had to be developed for the TTLS project to ensure the final prototype machine would be reproducible by Caltrans. Reproducing prototype machines is a different process that must be developed in tandem with research development process. Bringing a working prototype machine to a vendor for a reproduction quote after the fact is seldom successful. The prototype equipment will be so foreign to vendors that few vendors will take the risk and the ones that do will set the quote high to account for unknowns. The TTLS development process had a new set of procedures that focused on including vendors in every step of the prototype building process. In-house project resources were concentrated on design and engineering not building the prototype. Outside vendors were contracted to build the machines even though it took more time in some cases than completing the work in-house. This approach forces the design documentation to be accurate and complete to enable the vendor to complete the work. It also develops vendors capable of reproducing the parts of the machine they build, as well as other parts along the same expertise.

This development concept avoids the single vendor commercialization model that faces sole source purchasing restrictions. Instead, the fabrication work was broken down by type of work and spread out over several vendors. Therefore, to reproduce the prototype, Caltrans could obtain competitive quotes from these vendors, other similar vendors, or conduct the work with their own resources. Vendors would be responsible to warrantee their products individually. The overall machine assembly could be completed by a vendor or by Caltrans with the overall technical warrantee available through AHMCT. Technical, maintenance and operational support could be provided by AHMCT for the TTLS while deployed through an existing deployment support contract.

Common Components

SEALANT KETTLES

The success of any operation to apply hot applied sealants is directly tied to the performance of the sealant melting kettle used. The sealant melting kettles used for the TTLS project are based on standard oil jacketed style vats. A central vat is jacketed on all four sides and the bottom with heat transfer oil. A heat transfer tube runs through the oil jacket which provides a path for the burner flame to flow through. Hot applied sealants will quickly burn when exposed to temperatures very much higher than the recommended application temperature. Therefore, heat transfer oil is used to isolate the sealant from the high temperature of the burner. The temperature of the heat transfer oil is typically run at about a hundred degrees higher than the recommended sealant temperature. To further reduce the risk of localized burning, the sealant vat must have an agitator to keep the sealant flowing over the internal heating surfaces. A sealant pump provides for sealant flow for internal recirculation and application. A hot oil circulation pump is utilized to heat external sealant passages. Hydraulic motors power the agitator, sealant pump and oil circulator.

The operational procedure for the TTLS kettles is basically the same as any other standard sealant melting kettle. The burners heat the transfer oil to a preset temperature and then cycles to maintain this temperature while the sealant in the vat melts. As soon as the sealant pump is heated, hot sealant is pumped from the bottom to the top of the cold sealant mass to accelerate the sealant melting process. When the sealant mass is mostly liquid, the agitator is engaged. The burner will begin to cycle simultaneously to the sealant set point as well when the sealant reaches temperature.

Both the TTLS truck sealant kettle and the transfer trailer kettle were custom built specifically for this project. Unique TTLS kettle mounting and sensor port requirements precluded the use of standard commercially available sealant kettles. The transfer trailer frame was designed specifically to accommodate kettle pivot and load cell mounting. The truck kettle utilized load cell and pivot special mounts that bolted directly onto the chassis frame.

KETTLE MOUNTING

One of the chronic problems faced by all sealant kettles is a means to monitor accurately the sealant level inside the vat. Simple visual inspection is difficult due to vapor emissions caused when cold air comes in contact with the surface of the hot sealant mass. Opening the loading hatch for a visual inspection is very difficult to see and increases worker inhalation of the vapor. Direct mechanical means to monitor sealant level tend to gum-up and the environmental conditions inside the kettle are beyond the specifications of any direct level sensor. The TTLS project developed a means of monitoring sealant level based on measuring kettle outside weight. Kettle mountings were designed with pivots and load cells that produce a weight signal that can be sent to the PLC for processing. The full empty weights of each kettle is determined once and programmed into the PLC. The PLC can then display a simple to read empty to full bar graph on the user panel for the operator to monitor sealant level in the kettles.

PROPANE TANKS

To enhance air quality emissions for the TTLS system, propane fuel was the fuel of choice whenever possible. The TTLS system uses three identical 87 gallon propane tanks as a primary fuel source. One of these propane tanks is mounted on the TTLS truck to the outside of the chassis frame just rear of the driver side cab. The remaining two propane tanks are freestanding with lifting loops for use with the TTLS trailer. The trailer propane tanks have quick connect coupling on the supply hose that connects both tanks to the trailer to allow for easy connection. Caltrans maintenance suggested that two separate tanks would be more desirable than a single larger tank for the TTLS trailer. The dual tanks would allow the trailer kettle to be operated with one tank while the second tank is being refilled. For safety reasons, the propane tanks that fuel the trailer are not mechanically attached to the trailer. Instead these propane tanks will be transported in the truck that is towing the trailer in transport. The TTLS propane tanks have both vapor and liquid withdraw ports. It is the vapor port that is currently used.

PROPANE KETTLE BURNERS

Currently both the truck and trailer systems use approximately 500,000-BTU vapor propane burners to heat the kettles. The trailer kettle has two burners while the truck only has one. The vapor propane gas is supplied to the burner orifice at 30-psi. Igniter modules manage the automatic control of the burners to maintain maximum presets for the sealant and oil temperatures. Each burner is controlled separately and has a flame sensor to ensure the flame is present while the propane gas is flowing. Each burner also has a low flow solenoid valve for ignition and a high flow solenoid valve for after the flame is established. This minimizes the initial ignition flame. The PLC controls the overall burner operation and all system parameters can be changed on the user screen.

Each kettle has a set of thermocouples that provide a redundant over temperature safety switch for both the oil and sealant.

In operation the burner vapor withdraw rate compared to the size of the propane tanks causes the tanks to freeze at lower ambient temperatures. When propane tanks freeze the production of propane vapor in the tank is diminished, slowing gas flow and consequently lowering burner heat output. Since crack sealing operations are preferably conducted in the colder seasons when pavement cracks are at their widest, tank freezing promises to be a continuous problem. The standard method of mitigating this type of tank freezing is to switch to a liquid propane burner. Switching to a liquid burner system is beyond the scope of this project, but will most certainly be investigated in future development efforts.

SEALANT PUMP

Each kettle uses a 60-gpm hydraulic gear pump to circulate and apply the sealant. The sealant pump is attached to the inside top of the kettle lid and is directly driven by a hydraulic motor that sits on top of the kettle. A suction tube extends down from the pump which draws the hot sealant up from the bottom of the vat. The sealant pump speed is controlled by means of a proportional hydraulic solenoid valve. The operator can control the sealant pump direction and speed from in the cab on the user panel.

SEALANT BYPASS

It is standard practice when heating polymer-modified sealants to continuously circulate the sealant through the sealant pump while the kettle is heating. These kettles use a bypass circuit on the discharge of the sealant pump to direct sealant flow. The bypass circuit draws the hot sealant from the bottom of the vat and pumps it on top of the sealant mass inside the vat. The combination of sealant pump circulation and agitation keeps the sealant in the vat moving over the heating surfaces improving heating characteristics. To apply or transfer sealant, the bypass valve is closed which directs the sealant pump discharge to the kettle output passages. These kettles uses a pair of ball valves connected together, so that when one is open the other is closed. In this way, a single directional pneumatic cylinder can control the bypass. The function of the bypass is controlled automatically by the user program and a set of limit switches on the pneumatic cylinder provide feedback to the PLC of its correct position.

ELECTRIC OIL HEATERS

Both kettles have electric cartridge heaters that provide another way to warm the heat transfer oil. Each submersible electric heater is inserted directly into the heat transfer oil from both ends of the kettle. The cartridge heaters provide 2.5Kw of energy each operating on 240Vac power. The heat output of these heaters is considerably smaller than the propane burners, so they are of little use for directly heating the kettle. These heaters are useful though, to keep the heat transfer oil warm when the burner is off during transport and as an overnight oil warmer.

AUXILIARY ENGINES

A 25-horsepower auxiliary engine powers the hydraulic systems on both the TTLS truck and transfer trailer. The engine is capable of running on either propane or gasoline fuels. To minimize pollution concerns, propane fuel was the first choice of fuels whenever possible. The transfer trailer has propane as the only fuel source, therefore the auxiliary engine on the trailer operates on propane fuel. The propane version of the truck engine was not available at the time of purchase, so a gasoline version was considered the second best option. Therefore, the auxiliary engine on the truck can be operated on either fuel. The engine creates more horsepower on gasoline, so the engine is currently operating on this fuel, but it can be converted easily and quickly to propane upon request from Caltrans. This engine has an internal 12Vdc 15-amp alternator, which is used to supply operational power and to keep the system battery charged. Both auxiliary engines also utilize output shaft mounted alternators. The trailer version utilizes a 12Vdc 70-amp alternator to provide additional system operational power. The truck version utilizes a 24Vdc 60-amp alternator to power the electric application bar heaters. Any additional 12Vdc operational power required by the system is supplied by the dual alternator option that was purchased on the truck engine. For this reason the truck engine should be running when operating the TTLS truck kettle for extended periods.

Auxiliary Engine & Hydraulic Pump

The main purpose of the auxiliary engine is to power the hydraulic pump that supplies the hydraulic power to maximum horsepower output at 3,600-rpm. Gasoline/propane engines achieve maximum horsepower at higher speeds than does diesel engines. A diesel engine would attain maximum horsepower at about 2,300-rpm, which is why auxiliary engines are typically diesel engines. For this project Caltrans wanted to avoid the use of diesel fuel, so a gasoline/propane engine was chosen at an obvious cost, to power the various motors on the kettle. The maximum speed the hydraulic pump can be spun is 3,000-rpm before pump damage can occur. By limiting the auxiliary engine to 3,000-rpm, engine output power drops to about 17-horsepower. This leaves the auxiliary engine underpowered for the TTLS application requirements. Unfortunately, the auxiliary engine was the largest available from the kettle manufacturer that could run on propane fuel. The only short-term solution to the horsepower shortage is to reduce the number of motors operating at any one time to boost the power for the remaining motors. This can be easily and automatically accomplished with the PLC program focusing all the power where and when it is needed.

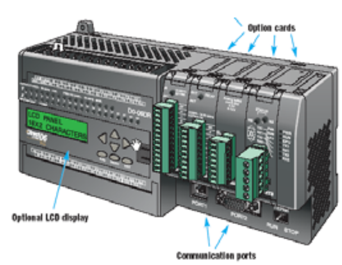
HYDRAULIC SYSTEM

A load sense hydraulic system was chosen for both the TTLS truck and transfer trailer for fuel efficiency and safety reasons. A load sense hydraulic system senses system loads and supplies the required pressure and flow to meet the demand up to a preset maximum. Under no load conditions, the system operates at a low preset standby pressure. This method of operation is ideal for TTLS where the hydraulic pump operates for long periods as the kettle is heating under no load conditions. The low standby pressure reduces the load on the pump thereby improving fuel efficiency and extending operation times given the limited fuel capacity. The low standby pressure, minimizes the chance of a hydraulic hose leak under maximum system pressure reducing the potential for safety and environmental hazards. In addition, the low standby pressure reduces the heating of the hydraulic oil and reduces the need for an oil cooler.

Each of the two TTLS hydraulic systems consist of three motors that drive the material agitator, oil circulator and sealant pump for each kettle. The truck circuit has an additional motor that drives a 240Vac hydraulic generator, but this motor only operates when the other three motors are off. The underpowered engine further limits the operation of the hydraulic motors that operate the kettle. The sealant pump has the greatest need for power and when the pump is running all other motors are temporary stopped to obtain maximum speed. The hydraulic valves are pressure and flow compensated and each valve stack contains a mixture of proportional and simple directional solenoids. Actuation of the solenoid valves are controlled directly by the PLC and can be accessed through the user panel by the operator.

CONTROLLER

The LCSM used a PLC to handle operator input and control the machine's sealing operations. The LCSM2 shared the same control features with extra functionality added to control the complex dual kettle operation. An in cab user input text screen was included on the LCSM2 so the operator/driver could directly control the dual kettles from inside the cab. These PLCs experienced years of field operation without any failures. The control system on both TTLS machines would also include the use a PLC, but would use a slightly updated version of the original PLC which



TTLS Common PLC

provided even greater functionality. The upgraded PLC includes four option module slots. These option modules were used to expand the control over TTLS far beyond what had been possible on the previous LCSM systems.

One of the major goals of the TTLS project was to conduct longitudinal crack sealing operations in moving lane closures. To accomplish this, the TTLS truck operator/driver would have to be capable of controlling and monitoring all necessary systems from inside the cab. Furthermore, many of the machine's functions would have to be automated to allow the operator/driver to focus on crack sealing and traffic when driving in live lanes. It was therefore necessary to develop a complex control scheme for the TTLS project that makes the complicated TTLS operation simple for the operator/driver to manage. The machine operator/driver will not see, or directly interact with the PLC, but will instead interact through a simple user interface.

SENSORS AND CONTROLS

For the PLC to be effective a wide range of sensors and controls were deployed on both TTLS machines. To meet the control and monitoring requirements for remote and automated operation, many inputs and outputs had to be developed for the PLC. Each PLC could handle eight input temperatures, four analog current inputs, two analog current outputs, several relay outputs and many digital inputs and outputs. Sensors include current, strain, temperature, proximity and voltage. The output controls are primarily voltage, but some analog output current controls were required as well.

USER INTERFACE

The user interface is an important new feature of the TTLS project. The TTLS is more complex than its LCSM predecessors and to have a chance to be successfully deployed in the field, a simplified operational procedure had to be developed. The user interface design has been evolving since the inception of the TTLS project and will continue to evolve throughout the field testing phase and possibly beyond. The goal of the user interface design is to simplify and automate as much as possible the actions of the TTLS machines. When completely developed the user interface would reduce training requirements, eliminate the need for dedicated operators, enhance safety and improve efficiency.

DISPLAY PANEL

Physically the user interface consists of a display panel that the operator uses to control and monitor the machine. The display panel used on both TTLS machines is an Automation Direct EZ-S8C-FSH eight inch color touchscreen LCD unit. The panel was designed to integrate with the PLC selected for the TTLS project. The display is designed for industrial applications and is very rugged. Unfortunately, the EZ display was not designed to operate in direct sunlight. Like all other commercially available PLC display panels, direct sunlight operation is not recommended and can cause damage to the LCD panel over a period of time. New LCD display technologies have been developed for PC's that operate in direct sunlight, but these products are slow to be adopted to the PLC marketplace. Eventually the sunlight displays will become available, but in the meantime the EZ panel will have to be protected. The TTLS Truck panel application is protected by tinted windows inside the truck cab. The transfer trailer panel application was more difficult to protect and may ultimately have a shorter lifespan. A protective shield has been fabricated to cover the panel when outside in the sun. It has a viewing slot and a hand can be reached up from beneath to touch the screen.

TTLS Common Display Panel

USER PROGRAM

The user program developed for the TTLS is defined as the operator/machine interface. The operator is provided only supervisory functional control over these machines via this user interface by way of the display panel. Essential information and choices are presented to the operator on custom designed user screens exhibited on the display panel and when the operator selects, the internal program control automatically configures and operates the required systems. The user screens change updating the essential information and selections as the operational sequence progresses. Hidden from the operator is an internal control program that is actually controlling the various systems that make-up the TTLS machines.

The user program is not a single program, but is actually comprised of two different closely related programs, one running on the PLC and the other running on the display panel. The PLC program handles program logic and system input and outputs while the display panel program acts as a logical PLC interface. Together these programs provide complete operational control over all onboard systems. The operator does not have the option to control any of the TTLS systems directly, since the TTLS does not have any manual override controls. By design, the operator's only option is to interact with the user program to operate the TTLS. The reason for this is that most of the system configuration and operational tasks are automated which drastically reduces the machines overall operational complexity. The concept is that as the sophistication of the machine controller increases, operator-training requirements decreases.

The most basic function of the user program is to provide control for the various components required to operate the TTLS machines. An initial set-up program was developed for both the TTLS truck and trailer that consisted of simple access to all input and output functions in order to test and verify the electrical and hydraulic system designs. Next, a basic program was developed for each machine that contained only the essential logic for full operation. The TTLS machines were operational at this point, but would require extensive training and operational knowledge to operate. Further development of the user program is in progress adding control logic that automates and simplifies machine operation. As the machines are being tested and the operational procedures and parameters are better established, more automation will be added to the user program further simplifying operating training. The ultimate goal is to develop a user program requiring little to no operator training for operators with some crack sealing experience.

With the establishment of a functional PLC control realized, a wide range of additional helpful features could be realized solely through programming without adding any additional hardware. Data logging, quality assurance, self-diagnostics and operator help resources are some of the most important of these features. Programming the PLC to record several important system parameters such as hours of operation, amount of sealant dispensed and temperatures is important data that Caltrans requires to determine the cost effectiveness of the equipment. The program can monitor application temperatures and advise the operator to ensure a good quality seal. The control program can both control and monitor operation in order to detect vital system failures and provide diagnostics resources to the operator. The user screens shown on the display panel offer informational help screens that when selected provides detailed information specific for each procedural step of operation.

Sealant life monitoring is also a function of PLC data logging capabilities, but is a large enough feature to be described separately. Hot applied sealants have a relatively short useful life at application temperature. As the sealant ages, it melts at increasingly higher temperatures until melt temperature exceeds application temperature and the sealant becomes a perpetual solid. This process of sealant aging is commonly referred to as sealant coking and leads to premature catastrophic equipment failures. The user program can be used to track the heated sealant life and inform the operator when the sealant life is short and must be emptied.

TTLS Truck Components

TRUCK CHASSIS

The vehicle platform chosen for this machine was the newly redesigned GMC C-Series chassis. After testing all commercially available cab designs, the new C-Series had the best driver ergonomics and visibility to the sealing shoe. The LCSM2 used a cab-over style truck, which caused ergonomic problems for the driver looking down at the sealing shoe. Therefore only trucks with standard, or low entry cab designs were considered for the TTLS project. The C-series offers a wide range of standard vehicle weight capacities. Following the recommendations of Caltrans Maintenance field personnel, the lowest reasonable capacity was selected to enhance vehicle on-highway maneuverability and low frame height. To keep the vehicle load capacity down the TTLS truck was not selected to be large enough to tow the TTLS trailer because this would have increased the chassis size significantly. A study of the operational procedure for the system showed this feature would not be necessary.

Conducting sealing operations off either side of the truck has become a required condition for a LCSM, therefore the new C-Series cab would have to have dual steering. Since the new C-Series was in its first year of production by GMC, custom options were unavailable and dual steering was obviously not a standard option. The Monroe Truck Parts company, which has a strong association with GMC was contacted in order to obtain a dual steer modification. Monroe Inc. had not engineered a duel steer option for the new C-Series, but they were interested in allowing this to be the first. The modification proved to be far more difficult than initially predicted adding to the delayed delivery of the modified truck by a year.

TTLS Ergonomic C-Series Cab

The dual steer option did include a full set of dual driver controls and indicators as was requested by representatives of the Caltrans Division of Equipment. The addition of the second steering by adding a cross shaft under the dash did make the truck a little more difficult to steer compared to the standard single steering version.

SEALANT PASSAGE

By design, hot applied sealants are solid at normal ambient temperatures. These sealants must be heated to over 300-degrees F to become a viscous liquid for application. Modern crack sealant dispensing equipment is usually equipped with passage heaters to heat the solid sealant in the passages to a liquid state enabling the sealant to flow through the equipment. There are many different methods employed to heat sealant with passage heaters and they can usually be divided into two categories, internal and external heaters. Each method has advantages, but over the years, most of the passage heaters built by AHMCT have fallen into the internal heater category. The TTLS machines utilize three passage heater systems and all three could be categorized as internal heaters, but are otherwise very different in nature. The reason for the different designs will be discussed throughout this report beginning with the truck sealant supply passage.

The sealant supply passage connects the output of the truck kettle pump to the applicator bar mounted on the front truck bumper. The source of heat chosen for this passage is the hot heat transfer oil in the kettle. This is a relatively free source of heat since diverting a small amount of hot oil from the oil jacket has little appreciable effect on the temperature of the large hot oil mass. The only draw on system resources rests with the addition of a pump to circulate the hot oil through the passage. The hot oil is pumped through a copper heating tube placed in the sealant passage in direct contact with the sealant. The copper heating tubing enters the sealant passage at the kettle pump discharge and runs the length of the passage to the applicator bar. At the applicator interface the copper heating tube loops around and returns back through the sealant passage and exits next to where it entered. In this manner, every inch of the sealant passage that contains sealant is heated; eliminating the possibility of cold sealant plugs, which would impede sealant flow. The hot oil is drawn from the kettle low where the oil temperature is higher, pumped through the sealant passage and then returned to the top of the oil jacket.

Oversized tubing was used to maximize sealant flow through the passage. The sealant passage consists of 1-1/2 inch steel tube and pipe covered with several layers of fiberglass woven insulation sleeve. A protective silicone coated fiberglass sleeve is the top layer that protects the insulation from road dirt and moisture. The temperature of the passage heat is controlled by varying the oil circulation speed. A hydraulic proportional solenoid valve drives the hydraulic circulator motor that is directly coupled to a high temperature oil circulator pump. Thermocouples on the sealant passage relay the passage temperature to the PLC. The operator can input the passage temperature set point on the user panel and the PLC automatically controls the passage temperature by way of an analog output signal to the circulator pump solenoid.

APPLICATOR BAR

The new truck cab design also necessitated a redesign of the applicator bar mounted to the front of the truck bumper. The LCSM2 cab-over truck had a short bumper to front axle distance. Since the sealing shoe is placed in line with the steering axle for optimum sealing shoe placement control related to vehicle tracking geometry, a special parallel link applicator linkage had to be designed to fit in. The new C-Series standard cab design had a longer bumper to front steer axle distance. This longer distance allowed for the use of a simple swing-arm applicator bar design that possesses a naturally superior shoe vertical tracking characteristic. Therefore, a new version of the applicator bar had to be developed for the TTLS truck. Since a redesign was in order, additional enhancements that have been emerging over the years of field deployment experience were incorporated into the new design also.

Previous applicator bar designs relied on a straightforward pneumatic cylinder to create the vertical lift of the sealing shoe arm. While this method produced the desired effect during sealing operation, during transport the field operators did not trust that it would reliably hold the shoe arm up. It became standard Caltrans practice to add a tie strap of wire, rope, or rubber bungee, to ensure the arm remained stationary when driven. The new design would have a lifting mechanism that would automatically lock in the retracted position, so even in the event of loss of air pressure the arm would not drop. To overcome this design challenge a fundamental change was made in how the arm was lifted. Instead of lifting the shoe arm relative to the bumper cross bar, the cross bar would consist of two segments that rotated axially. The shoe arm was fixed to the rotating end of the cross bar, creating lift. A sliding pin and “V” collar arrangement created the rotation between the two cross bar segments. Translation of the “V” collar by extending dual air cylinders creates sealing shoe lift.

Applicator Bar Stowed For Transport

Hot sealant is conveyed to the applicator bar via the heated sealant passage system that connects the sealant kettle to the applicator bar on the front bumper of the truck. Like the sealant passage, the sealant passage through the applicator bar must also be heated to ensure the sealant within is hot and liquid. For this application, internal electric cartridge heaters were employed. Since the applicator bar design consisted of several rotating sections, each segment would have an individual cartridge heater that would allow for rotation. There are five electric cartridge heaters of various lengths inserted directly into the sealant applicator passages such that every inch of passage is directly heated.

The applicator bar cartridge heaters are powered by a 24Vdc alternator connected directly to the auxiliary power engine. There are five cartridge heaters of various lengths connected in two independently controlled series loops. The cartridge heaters were designed to have a set resistance value per length, so that the temperature of all the elements in each series loop would be the same. Therefore, to control the temperature of the cartridge heaters, only a single thermocouple needs to be attached to any element in each of the two parallel circuits to relay the temperature of the entire loop to the PLC. The operator can set and monitor the applicator passage heaters from the user panel in the cab. The PLC program controls the applicator bar passage temperature automatically.

The applicator bar is usually folded into its stowage configuration when not in use. The applicator bar bumper mount was designed with a cradle to eliminate any possibility of the shoe dropping during transport. In the stowage position, the applicator bar locks into the cradle on the front bumper for safe transport and folds the bar so it does not protrude from the side of the truck. A pushbutton is mounted on the front of the applicator bar, which releases the lift collar to allow the applicator bar to be lifted into its locking cradle. The applicator bar should be heated approximately 30 min prior to the beginning of sealing operations to a operating temperature of approximately 400-degrees.

The applicator bar should be heated before repositioning is attempted. This allows the joints to move freely making it easier for the operator to reposition the applicator bar and protects the internal heating elements. A safe method of insulating the applicator bar was an important design consideration to mitigate the potential of burns when folding. The applicator bar design chosen for the TTLS uses a double shell approach. The internal sealant passage is comprised of a copper tubing passage with brass rotating flange joints. The outer casing consists of steel and aluminum pipe with connector swivel blocks. The outer casing provides the required rigidity and mounting surfaces and the inner shell is the heated sealant passage. An air gap is maintained internally between the inner and outer shell as an insulating layer. The inner passage can be hot while the outer casing remains cool to the touch. Additionally the outer casing is all metal and therefore very rugged. Spring pins lock into detents in the casing blocks to configure the applicator bar in position. Pushing down on the handles allows the joints to rotate freely to reposition the applicator bar.

TTLS Sealing Shoe

SEALING SHOE

One of the major benefits of using the LCSM for longitudinal sealing is the uniform tooled appearance of the seal produced by the machine. The sealing shoe attached to the business end of the applicator bar is responsible for producing the attractive seal appearance. The sealing shoe is very similar to the common hand sealing squeegee. The main difference is that the LCSM delivers the sealant directly into sealing shoe. The sealing shoe on the TTLS shares many of the same features as the LCSM, with one major improvement. A pinch plate has been developed to positively stop the flow of sealant from the applicator tip when the sealant pump is stopped. When the sealant flow was stopped before on the LCSM and LCSM2, the sealant would continue to run and drip due to gravity flow. Providing a means to mitigate the dripping would further improve the seal appearance on the highway.

The deployed applicator bar extends along the side of the truck from the bumper to a point inline with the front axel and about 20 inches out from the side of the truck. The sealing shoe is connected to the end of the applicator bar with a pivot mounting that allows for the unevenness of the roadway. The width of the sealing shoe varies depending on the preferences of the operator and the specifics of the crack to be sealed. The shape of the shoe also affects the width of the seal if a constant or variable width of seal is desired. A high temperature reinforced silicone rubber material provides for the compliant contact material to the pavement. The rubber strips tend to wear very slowly, but the shoe is designed to make replacement with new rubber strips easy and straightforward.

TRANSPORT HARDWARE

In the typical longitudinal sealing operation, the sealant kettle is heated to operational temperature off the highway before being brought out onto the highway to seal cracks. This process takes several hours and is timed to coincide with the availability of the road maintenance window on the highway. Caltrans safety rules restrict the operation of a propane burner when the kettle is being transported over public roads. Therefore, the kettle temperature experiences a significant drop as the kettle is transported out to the highway with the burner off. When the kettle arrives at the work zone, additional time is required to recover the kettle to operational temperature using the propane burner. To reduce, or eliminate the reheat time on the highway, the TTLS truck has been designed with an electric heater system intended to maintain kettle temperature when the burner is switched off during transport.

The transport heater system consists of a hydraulic generator, three electric cartridge heaters and a user control program. In theory, the auxiliary engine only has the capacity to power the generator, so all other hydraulic motors are stopped when the heaters are engaged. In practice, the engine can only power half of the heaters without drawing down engine speed. The operator/driver can select the truck transfer configuration by selecting it on the user screen in the cab. The PLC program then automatically configures the TTLS truck for safe highway transport. The mobile configuration stops the propane burner and engages the hydraulic generator. Upon reaching the highway work zone, the operator presses a button on the user screen and the PLC returns the TTLS truck to the normal heating operation.

TTLS Trailer Components

TRAILER CHASSIS

The TTLS transfer trailer consists of a 600-gallon oil jacketed sealant melting kettle connected to a trailer chassis via a load sensing pivot mounting. The trailer channel frame surrounds the kettle such that the kettle mounting channels nest within the frame. This allows for rotation movement and at the same time captures the kettle within the trailer frame in case of an accident. The trailer channel frame extends several feet to the front providing for mounting space for the auxiliary engine, burners and various reservoir tanks and support equipment before necking down to the hitch point. For safety reasons propane tanks were not mounted to the trailer because the trailer frame would not adequately protect the cylinders in case of a collision.

The TTLS trailer must be towed with a medium duty or larger truck, for instance a Caltrans four yard dump truck is a very common vehicle found in just about every

Caltrans maintenance yards statewide. The most common Caltrans fleet trucks in this size range are typically fitted with trailer air brake systems. Therefore, the TTLS transfer trailer has a air over hydraulic brake system, since the trailer axles load ratings were in the standard hydraulic brake range. To provide for parking brakes when the trailer is not hitched to a truck, an onboard air compressor and storage tank maintains brake system air pressure. The transfer trailer uses a Caltrans standard seven pin trailer lighting connection, but is self-contained and does not draw any auxiliary electrical power from the towing truck.

HOT SEALANT TRANSFER

Hot sealant transfer is the sole function of the TTLS trailer kettle. Therefore, the development of a transfer system capable of fast, reliable and safe hot sealant transfer to the application truck was essential. To accomplish the fast sealant transfer, a large capacity sealant pump was coupled with oversized passages to develop a high flow rate for a fast transfer time. To ensure reliable sealant transfers, a method to prevent the kettle from being overfilled with sealant had to be developed. Overfilling was a persistent problem with the LCSM2, which transferred hot sealant between its trailer mounted melter kettles and periodically resulted in overfilling two with hot sealant spilling out of the loading hatches. Since the TTLS is designed to fill a smaller kettle from a far larger kettle, the opportunity for overfilling is even more inherent. PLC control was extended to the TTLS transfer process in order to mitigate the overfilling problem. The PLC on the transfer trailer is the controller that manages the sealant transfer process. The sole task the TTLS truck contributes to the transfer process is the transmission of the truck kettle sealant level to the trailer controller via a wireless signal. The trailer controller receives the wireless signal and during hot sealant transfer, continuously monitors the truck kettle level. Sealant transfer terminates automatically when the truck tank is full, and transfer will pause if the truck level wireless signal is lost, or interrupted. Another potential cause of overfilling arises from the practice of re-circulating sealant through the transfer hose while heating. The final step in the transfer hose heating procedure is to pump hot sealant from the trailer kettle though the hose and back into the top of the trailer tank. Should the transfer hose be mistakenly connected to the truck in this process, the hot sealant would be transferred to the truck without any sealant level control. To eliminate this possibility, a proximity sensor determines if the transfer hose coupling is connected to the trailer kettle for continuous recirculation, or connected to the truck for controlled filling with tank level monitoring.

TTLS Hot Sealant Transfer

Safety is always a major concern when pumping hot sealant, but this is even more important when conducting high speed transfers. The potential for the hot sealant flowing, or dripping onto a worker handling the equipment causing nasty burns is chronic. Adding manual safety valves and controls can reduce the hazard, but the possibility of an operational mistake leaves these approaches far from secure. A fail-safe transfer method had to be developed to ensure that worker safety could be assured. Once again extending the capabilities of PLC control was the solution at hand. A series of redundant sensors and controls were developed that would allow the PLC to continuously monitor the transfer process to instantly sense an unsafe condition and immediately terminate hot sealant flow.

TRANSFER HOSE

The transfer hose is the conduit that connects the TTLS trailer to the truck kettle for transferring hot sealant. Since the applicator truck is mobile and operates independently, a simple connection method had to be developed that did not require the truck to physically mate with the trailer. The goal was to develop transfer hardware so the application truck need only to be parked near the trailer for filling. Since transfers rarely take place on perfectly flat surfaces, the transfer connection had to be flexible enough to adapt to unpredictable positions and orientations of the truck. To meet these requirements a flexible hose was selected over a rigid swivel pipe design. The transfer hose can be easily aligned and coupled anywhere within reach of the hose. The transfer hose couples to the top of the trailer tank for storage and recirculation. For truck transfer the hose is decoupled from the trailer and swung over to the truck and coupled to a fill spout on the top of the truck tank. Since the truck tank is a couple feet higher than the trailer, the transfer hose is attached to the trailer via a rotating coupling mounted at an angle, so as the hose swings it also gains height. A support arm supports and swings with the hose.

TTLS Transfer Hose

The transfer hose consists of a flexible steel braided convoluted Teflon hose with specially designed coupling ends. The overall length of the transfer hose is seven feet long and consists of an inner and an outer shell. The inner shell is the heated sealant passage with a large 1-1/2” ID allowing for high material flow. The outer shell is the protective and insulating cover that provides mounting structures at its ends. The middle section of the hose is fully insulated and covered with a protective sleeve. The transfer hose ends have an air gap insulation layer between the sealant passage and the outer shell casings that reduces the outside surface temperature insuring that the hose can be handled safely by hand, even barehanded. Since the TTLS was designed to apply hot applied sealants, the transfer hose contains an internal hot oil circulation circuit to heat the sealant passage. Hot heat transfer oil from the kettle oil jacket serves as the heat source for the hose heater. A circulation pump circulates the hot oil from the kettle through flexible steel braided Teflon tubing running inside the hose to the end and back before being returned to the oil jacket. The speed of the circulator pump controls the heating speed and temperature of the hose passage. The user program automatically controls the hose heater to maintain a user defined set-point temperature. Safety systems were incorporated into the design of the transfer hose providing for a rugged and clean hose exterior. Burns are the primary hazard associated with the transfer hose and have two primary sources; one results from pumping hot sealant through the transfer hose when the exit coupler is not securely attached to a kettle fill spout and the second is related to hot sealant dripping from the transfer coupling when changing the connection destination.

It is essential that the machine controller have the capability of sensing when the transfer hose coupler is properly connected to the kettle fill nozzle. The user program can then be utilized to verify a secure coupler connection exists before pumping hot sealant through the transfer hose. Should the controller sense the coupling has become unsecured, the sealant pumping will be immediately terminated. A cam and groove coupling makes the hose connection at the free end of the transfer hose. The brass locking cams have been modified to sense contact to the brass fill spout, which is isolated electrically from the kettle. The cams also use magnetic sensors to verify a locked position. Using the two cam sensors and logic, the user program can reliably determine the status of the coupling connection.

Incorporated within the transfer hose coupling is a poppet style valve designed to positively block the sealant passage. This poppet valve is a redundant safety measure that prevents hot sealant flow in the event of various types of system malfunctions. The controller must open the poppet valve and then sense the valve is open before engaging the sealant pump. Should the sealant pump engage in the case of a malfunction, the poppet valve prevents hot sealant flow. A dripping hazard was mitigated with the low-profile design of the poppet valve seat. Disconnecting the hot transfer hose coupling, typically results in hot sealant dripping from the coupling. This can lead to minor burns for the worker handling the transfer hose. The poppet valve was placed flush with the end of the sealant passage in the coupler body, such that when the valve closes no sealant remains to drip.

NIGHT HEATER

Sealant kettles can be heated up to operating temperature much quicker if the heat transfer oil and sealant are already warm. A night heater is a means to ensure the kettle is kept warm and typically consist of electric oil heaters with automatic control powered by an external source. A night heater system was developed for the TTLS transfer trailer only. Since both TTLS kettles have electric oil heaters installed, both could have had night heater systems, but to simplify the truck controller this feature was not installed on the truck prototype. The additional electronics required for the night heater are significant, due primarily to the development of an automatic AC power sensing circuit. This system senses when the external AC power cord is plugged into an external 240Vac source. The controller then automatically reconfigures the transfer trailer for, and only for, night heater operation. Regardless of where the PLC is in the transfer trailer's operational process, when external power is connected, the user program jumps to the night heater screen. To return to the main program, the external power source must be disconnected.

Night heater operations typically take place overnight and are usually unsupervised. A special hardware configuration had to be developed for the trailer controller to allow for this type of operation. The trailer controller normally operates on the onboard 13Vdc electrical system, but running the night heater requires that the controller also be capable of operating completely on the external 240Vac power to protect the battery. A DC power supply was included to provide enough DC power to operate the essential electrical components and systems needed to conduct night heater operations. This special configuration switch depends on a series of interconnected relays that add significant complication to the transfer trailer controller electrical system.

As the transfer trailer is being electrically configured for night heater operation, a timed heater operation program is presented on the display panel. The operator can enter a desired starting time and day, duration and set point temperature for the electric heater operation. The electric heaters can be turned-on and off automatically by the PLC.

TTLS System Operation

TTLS OPERATIONAL REQUIREMENTS

The TTLS was developed to be a high production, large capacity longitudinal highway crack sealing machine. What was equally as important is that the machine developed would also have to be capable of integrating into the existing Caltrans maintenance operations. To increase the deployment potential for research equipment, AHMCT long ago adopted a policy of development within traditional worker procedures. Even though it is typically easier, from an engineering standpoint, to change worker procedures to simplify machine design considerations, the new sealing machine concept had to address significant restrictions based on the common structure of Caltrans maintenance crews, safety procedures, work force limitations, operational windows, responsibilities and preferences. The importance of operational procedure alone would prove to be as important as the development of functional hardware for the TTLS project.

Since the TTLS concept was in general based upon an observed Caltrans maintenance crew LCSM2 nurse kettle operation, this operation would in general serve as the TTLS operational procedure model as well. For small crew operation, as few as two, or three workers could operate the TTLS on the highway. With the addition of one worker, the operation of the transfer trailer could be included, which would more than double the seal production capacity. The transfer trailer would typically be operated at a safe place off-highway, but transfers could be preformed either on-highway, or off-highway based on user preference. The TTLS operation eliminates the need for a worker to ride on the back of the truck loading sealant blocks while the truck was moving which was implicit to the LCSM operation. Furthermore, since the TTLS truck operation can be completely controlled from inside the truck cab, any direct traffic worker exposure is eliminated altogether. With sealant transfers being conducted off-highway, the entire crack sealing operation can be conducted without any direct traffic worker exposure on the highway.

TTLS Basic Operation Description

As in any road maintenance operation conducted on the highway, workers need to understand the scope of the task at hand and develop an operation procedure to safely accomplish the days objective. To operate the TTLS workers need to follow this same procedure. All involved must understand issues such as the amount of material needed, work zone configuration and job duties before the operation begins. The workers operating the TTLS truck and transfer trailer must also be familiar with the operation of the equipment and have pre-established procedures to follow should equipment failures occur.

Estimating the amount of sealant required to meet the days sealing goals is an important first step when utilizing the TTLS. Should the days sealing needs require up to four hundred gallons of sealant, the truck kettle alone is capable of supplying the sealant. Should the job require more than four hundred gallons of sealant, the transfer trailer should be operated in tandem with the truck. The truck kettle cannot realistically be expected to melt any more than the tank capacity, because the kettle is empty and will not recover for many hours. Should the sealing job require less than eight hundred gallons of sealant, or two application truck loads for a days operation, then the trailer should be shut down after the days initial sealant transfer. For very large sealing jobs requiring more than eight hundred gallons of sealant, or three or more application truck loads, the transfer kettle should be continually refilled and recovered.

Common Kettle heat-up Procedures

Few systems function on either of the TTLS machines when they are at normal ambient temperatures. The TTLS machines must be brought up to operational temperature for the machines to operate. The machines are typically heated and filled with sealant off the highway, or in the maintenance yard and only after reaching operating temperature are they brought out to the work zone for sealing operations. The truck kettle heating process start time is calculated by working backward from the desired sealing start time by subtracting the kettle heat-up time. Often times an operator is scheduled for an early start time on sealing days in order to start the heating process at a sufficiently early time to reach the desired highway sealing start time. The transfer trailer kettle has a larger heat-up time window because transfer would typically occur after the combination of truck heat-up and application times.

The first step in the kettle heating process is to start the propane burner which heats the heat transfer oil. A major part of the overall kettle heat-up time is devoted to brining the oil up to temperature. Once the oil reaches set point temperature, the propane burner will cycle automatically to maintain temperature. The hot oil jacket distributes heat evenly over the internal sealant vat surfaces slowly conducting heat into the solid sealant mass. First, the sealant directly in contact with heated surfaces melts followed by the solid sealant mass melting from the outside in. As soon as the sealant pump and passages heat-up, the pump is automatically engaged drawing the melted sealant off the bottom of the vat and pumping it up on top of the sealant mass. This sealant recirculation helps heat the sealant pump and speeds the melting of the sealant mass. The sealant agitator engages automatically at predetermined sealant mass set point temperatures, which is set at the temperature, where the sealant mass in nearly liquid. The sweeping motion of the agitator is most effective at recirculating the sealant in direct contact with the kettle internal heating surfaces reducing the risk of sealant burning and ensuring a more homogeneous sealant mass temperature.

When the sealant reaches the user defined set point temperature, the burner will automatically begin cycling to maintain the sealant mass temperature. The sealant bypass pump and agitator remain running to circulate sealant in the kettle while the kettle is in operation and at temperature. Safety switches on the sealant loading hatches pause the agitator when the hatches are opened to mitigate the possibility of splashing hot sealant out of the kettle. To discharge sealant from the kettle, the sealant bypass valve closes and the discharge valve opens allowing the hot sealant to flow out of the kettle. A pneumatic cylinder and linkage provides the simultaneous positioning of the bypass valves controlled by the PLC and User Program.

There are several ways to terminate kettle operation. Under normal operating conditions, the user screen provides buttons to step out and terminate machine operation. Machine operation will also terminate automatically if system power is interrupted, or shut off. In case of an emergency, several emergency stop buttons are available at various important locations around the machines. The emergency stops will immediately stop all machine functions and kill system power. The user screen will display an emergency stop screen along with a message for the operator to twist reset the emergency stop switch to return to normal operation. In all of these cases, terminating machine operation also stops the auxiliary engine from running.

APPLICATION TRUCK OPERATION PROCEDURE

In addition to the common kettle heat-up procedure, the TTLS application truck has an additional sealant passage-heating step to be completed to get the machine ready to conduct sealing operations. Again, working from the desired sealing start time on the highway and subtracting the passage heat-up time, the user program can automatically begin the heating process. There are two passage heater systems. One uses internal hot oil tubing to heat the sealant passage that runs from the kettle discharge to the applicator bar. The second is a series of electrical heaters that heat the internal sealant passages through the applicator bar. Both of these passages must be heated up to recommended sealant pour temperatures to ensure proper sealant flow and that the desired exit temperature is maintained.

Caltrans safety restrictions prohibit the operation of the propane kettle burner when driving on public roads. Burner operation on the highway is only permitted within safe work zones. Therefore, the user program on the application truck has a special mobile operation configuration selection that automatically configures the machine for operational transport. The program turns off the kettle burner and engages electric heaters powered by the hydraulic generator to maintain system temperature as the machine travels down the road. As the machine enters the highway work zone, the configuration is switched back to normal burner operation. The generator requires all available hydraulic power to function, so agitator and bypass operations are also paused for the operational transport configuration and automatically restarted when the configuration switches back.

The applicator bar mounted on the front bumper of the application truck delivers hot sealant to the sealing shoe. The TTLS truck is dual steer and the application hardware is designed to operate off either side of the vehicle. The side of operation would be typically configured before leaving the field station yard, but the sealing shoe would remain in the folded position for transport. The applicator was designed to lock into a cradle for transport, ensuring the applicator cannot become loose in the event of any, or all system failures. Depending on work zone specifics, final sealing shoe deployment could be conducted in the work zone, or off the highway on the exit just ahead of the work zone. A lifting collar locks the sealing arm and shoe in a fail-safe position when raised. The collar can be retracted manually for unfolding by pressing a release button mounted in an easy to access spot on the bar’s main pivot. The collar when retracted allows the applicator bar to rotate and gravity lowers sealing shoe to the pavement. The collar retracts completely allowing the shoe to free float on the road surface and follow the contour of the pavement. The sealant discharge nozzle pours sealant into the shoe forming a sealant mass that is pulled along the crack sealing all voids. A spring plate pinches the tip of the nozzle preventing the sealant from dripping out when the sealant flow is stopped.

The application truck operator/driver controls the sealing operation with a handheld wireless remote control. The operator can raise and lower the sealing shoe, start and stop the sealant flow and control the sealant flow rate, all by remote control. The control scheme is very similar to the very popular LCSM2 controls that enable the user to cycle through the normal series of application events by pressing a single button. Another button reverses the cycle and the remaining two buttons adjust sealant flow rate. The display panel illustrates the function of the buttons on the remote control during each of the different phases of operation and functions as a redundant set of applicator controls to backup the remote controller. The display panel also presents vital system information to the operator that is pertinent and stage specific.

The TTLS application truck is designed to apply large amounts of sealant on the highway. The truck kettle can be refilled either directly with sealant blocks through a loading hatch, or by hot sealant transfer from the TTLS trailer. Depending on job specifics, direct loading, transfer, or a combination of both may be advantageous. In general, sealant blocks would most likely be loaded directly into the truck kettle during initial system heat-up to fill the kettle. Direct block loading at the end of a days sealing operation was a very efficient stragetity pioneered in the LCSM program. The last task after the hot kettle was shut down was to stuff as many sealant blocks as possible into the tank. The next day the residual heat melted the blocks down and made room for more blocks during heat-up. This process shortened the kettle filling procedure. Hot sealant transfer would be best utilized for mid-day refilling of the applicator truck to keep the sealing operation productive. Hot sealant transfer avoids the long hours of delay experienced when attempting to melt sealant blocks during a day's operation.

The TTLS truck is a passive participant in the sealant transfer process. The kettle controls the transfer process. The truck is simply parked along side the trailer, driver side to driver side. The transfer hose is long enough that the placement of the truck is not critical, as long as the fill nozzle is within reach. The truck's filling nozzle was located on the roof of the kettle to permit sealant transfer regardless of the status, or temperature of the truck kettle. The sealant level of the truck tank is measured by the integral load cell mounting and broadcast to the transfer trailer via a wireless signal.

APPLICATION TRUCK HIGHWAY OPERATION CONSIDERATIONS

The ideal longitudinal crack sealing operation would require a minimum of labor to seal a maximum distance of crack in a short period of time. The hardware developed for the TTLS project includes a means to provide for significant advancements in all three of these factors, but innovative hardware alone is not a guarantee of success. Operational procedures must be developed to realize the full production potential of the new equipment on the highway. New functions have been incorporated on the TTLS to provide the operator with new capabilities to conduct more efficient sealing operations on the highway. Maintenance crews need to evolve their standard sealing operation strategies as the equipment has evolved to meet user production demands. This evolution process was evident when Caltrans maintenance crews seeing the potential, created a longitudinal crack sealing operation running the LCSM2 down the shoulder adjacent to live traffic lanes, dramatically decreasing the overall costs of sealing. Procedure innovation was also evident when Caltrans maintenance crews created the LCSM2 nurse kettle operation in an effort to extend production capabilities. New TTLS design features will facilitate the development in the field of additional innovative crack sealing procedures to further improve sealing production capabilities and efficiency.

As defined by the TTLS strategy, improvements in sealing production capacities have primarily become a transfer trailer hardware issue and only indirectly associated with truck operational issues. Improvements in efficiency on the other hand are generally associated with the seal application process, which link it implicitly to application truck operational issues. As for sealing hardware improvements, only incremental improvements to the LCSM2 hardware remained, which could only produce limited increases in efficiency. To achieve a large increase in efficiency, operational procedures had to be developed that increases the ratio of work time actually spent productively sealing cracks at the expense of ancillary tasks, such as establishing a work zone. By definition overall efficiency skyrockets, when all the time on the highway is spent sealing cracks and becomes even more profound when cracks between lanes, currently inaccessible because of procedural problems, can be sealed. Using the TTLS Caltrans maintenance sealing operations will be able move beyond limited shoulder sealing operations and out between lanes where multiple lane closures are deemed too costly and obstructive.

MOVING LANE CLOSURE OPERATION

TTLS advancements in the area of improving efficiency center on the development of a machine capable of moving lane closure operation, which promises to be the ultimate goal in maximizing sealing efficiency. A longitudinal sealing operation for several reasons will realistically never exceed the five to ten mph range. This is the approximate speed of current Caltrans longitudinal paint striping operations that routinely operate in moving lane closures statewide. To overcome the high likelihood that slow moving closures will create traffic back-ups, moving lane closure operation have the inherent ability to exit the highway as needed to minimize traffic impact. Moving lane closures require virtually no setup, or take-down resources. The overall efficiency is optimum, because all the time on the highway is spent sealing cracks.

Typical moving lane closure consists of the vehicle conducting the work, followed by a couple of large attenuator trucks and trailing the operation is a sign board truck. The vehicles spread out at about thirty feet spacing with the gaps varying for the application to change speed if needed and still maintain a constant speed for the last trailing attenuator truck. The trailing sign board truck follows and drives along the shoulder adjacent to the lane being closed indicating that traffic must merge. These vehicles line up off the highway, pull out taking the lane last vehicle first, and leave the closure in the reverse order. An additional truck can be sent to temporally close any ramps that are crossed by the moving lane closure as they are being passed. The sealing vehicle can vary speed as needed, but cannot stop for any length of time and certainly the operator cannot leave the vehicle.

To make it possible for the TTLS application truck to operate in a moving lane closure operation on the highway, the operator must be capable of controlling all sealing functions from inside the truck cab. The LCSM machines provided basic functional operator controls inside the cab, but a majority of the controls remained on the kettle. The TTLS would be the first of any known kettle that placed all functional controls and instrument information inside the operation cab. For the prototype, only the starting of the auxiliary engine function was excluded from remote control. All remaining functions from burner operation, heating systems, sealant bypass to the entire application process, is controlled from inside the cab. The operator also needs to monitor the operation and status of all sealing hardware from inside the cab. A wide array of sensors were deployed on the sealing truck in order to present all essential system temperatures, tank levels and error conditions on the display panel in the cab. Once the sensor systems were developed, additional sensors were easily added to further enhance machine control. One of the most important of these newly added features is the sealant exit temperature. A sensor measures the temperature of the sealant discharge into the sealing shoe to ensure the sealant is being applied at the manufacturers recommended application temperature to ensure a high quality seal.

When sealing longitudinal cracks in a moving lane closure, it is essential that a release agent be applied to the surface of the seal. Hot sealant sticks better to tires than it does to pavement. If vehicle tires run over fresh sealant, the seal will generally pull off the pavement and stick to the tires. Any traffic following the sealing operation that changes lanes could potentially pull up the sealant, which would stick to tires presenting several hazards. A light mist of a liquid release agent sprayed on the surface prevents the sealant from sticking to tires. A tire impression will be left in the sealant over band, but the seal integrity will remain. Specific use water soluble products are available as a sealant release agent, but plain water works well enough for most situations. Many scenarios could be employed to apply the release agent in the moving lane closure operation, with installing the sprayer on the application truck being the most efficient. A small scale water tank, dual side spray system and integrated controls were added to the application truck for testing purposes.

CRACK CLEANING STRATEGIES

Good crack sealing procedures usually include the cleaning of pavement cracks prior to the application of sealant. The removal of dust, dirt, loose debris and vegetation from the crack pocket enables the seal to adhere to all crack surfaces increasing seal effectiveness and longevity. Crack cleaning can generally be considered a standard crack sealing practice. During the development of the initial LCSM with its increased seal production rate, questions arose as to the need to develop new strategies to clean the increased distance of crack. This would not turn out to be an issue, because Caltrans maintenance were already using quick and effective crack cleaning methods suitable for increased seal production. The limiting seal production factor turned out to be the application of sealant and not the cleaning of the longitudinal cracks. Even when the LCSM dramatically increased seal production, crack cleaning never became a limiting factor to influence seal production. Caltrans maintenance crews varied their crack cleaning methods depending on the degree of cleaning required. Crack cleaning operations are lower priority and do not rate high enough to justify lane closures. Therefore, Caltrans conducts these cleaning operations from the shoulders and adjacent to live lanes.

For longitudinal cracks requiring heavy cleaning, Caltrans may visited a crack several times out on the highway before it was deemed clean enough to send the sealing crew out to seal it. A truck towing a rental air compressor would be sent out to blow debris from the cracks days ahead of the sealing operation. Two hoses were connected to the air compressor. One hose was run to the driver door where it temporally mounted so the air blast could be aimed directly down into the crack loosening and blasting out all loose debris and vegetation. The second hose was mounted to the rear of the air compressor trailer were it would blow any dislodged debris that landed on the traffic lane far off onto the shoulder. A sweeper would later in the day be dispatched to remove all remaining debris from the shoulder. Should vegetation remain in the crack, another truck would be dispatched to apply herbicide in the crack. After the herbicide was given enough time to kill the vegetation, the air blast operation was repeated. Typically, a final blowing operation was conducted just ahead of the sealing operation to remove any dust that may have settled in the crack, optimizing seal adherence.

Should the longitudinal cracks require only a light cleaning to remove dust and not debris, a blowing operation just ahead of the sealing operation may be all that is necessary. Caltrans always utilized a separate vehicle for any blowing operations. Since the light blowing operation was much faster than the sealing operation, a worker could blow out enough longitudinal crack for an entire day’s sealing quickly and be assigned to other duties. The TTLS may be configured to conduct this light blowing operation in conjunction with the sealing operation, further reducing manpower requirements. Since the truck sealant kettle is vehicle mounted, a rental air compressor could be towed behind the TTLS truck. A compressed air discharge hose could be run just ahead of the sealant application shoe blasting dust from the crack just ahead of the sealing. The combined blowing and sealing would only be effective when dusting the crack. Any heavier debris in the crack could be blasted into the trailing sealant reducing seal quality. The heavy cleaning operation would still be required in most cases as a separate operation. The combined operation should best be limited to the light dusting that optimizes seal adherence.

A trailer hitch is not currently installed on the TTLS truck. A decision was made not to include a hitch that could be utilized to tow an air compressor. Since the TTLS truck GVW is too small to tow the TTLS trailer, not including a hitch eliminates the possibility that someone may overload the truck. In addition, it is not clear that Caltrans maintenance crews will actually prefer the combined blow and seal operation over the current separated method. In deployment, should Caltrans maintenance express an interest in experimenting with the combined operation, provisions have been made to add a hitch in the future.

TRANSFER TRAILER OPERATION PROCEDURE

TTLS advancements to dramatically extend sealing production capabilities center on the hot sealant transfer concept. The basic theory of operation is that the trailer kettle provides a hot sealant reservoir used to refill the application truck kettle thereby extending production. For larger sealing jobs, the trailer kettle can be heated in tandem with the application truck kettle. When the application truck has applied its supply of hot sealant on the highway, the hot trailer kettle can quickly transfer another full load of hot sealant to the truck kettle for continued sealing operation.

The basic heat-up procedure is followed with a transfer hose heating process. Hot oil heating tubes run along the inside of the transfer hose and heat the sealant line from the inside out. Working from a user supplied transfer time and subtracting the hose heat-up time,

the hose heaters automatically begin the process. The hot oil circulator pump engages and heats the solid sealant in the transfer hose. When the sealant becomes liquid in the transfer hose, the sealant bypass valve closes automatically pumping hot sealant though the transfer hose in a recirculation process. This ensures that the hose is hot and ready for transferring.

The application truck is parked alongside of the trailer kettle such that the transfer hose can reach the filling spout on the truck. The operator conducts the transfer process from the trailer display panel. The operator selects the transfer operational screen, sealant recirculation is terminated and is prompted to connect the transfer hose to the truck kettle. Once the controller senses the transfer hose is connected and locked to the truck tank, the transfer begins. Since the trailer controller is monitoring the sealant level in both tanks, the truck tank will automatically fill and stop when full. With the transfer complete, the transfer hose is returned to the trailer recirculation spout and locked. The trailer display panel returns to the basic heating operation for sealant recovery, or shut down.

Safety was a primary concern in the design of the transfer trailer. The potential risk of serious worker injury is serious when working with large flows of very hot material. Several safety devises were designed and incorporated into the transfer system design to mitigate this hazard. The most important of which is that the flow of hot sealant is immediately terminated when sensors indicate that the transfer hose coupling may not be, or possibly has become unlocked. Termination of flow will be accompanied with an audible alarm and a message on user panel describing the fault and a remedy.

TRANSFER TRAILER OPERATIONAL CONSIDERATIONS

The transfer kettle was designed to be filled with Caltrans standard hot applied sealant blocks. Two loading hatches in the roof of the kettle provides a splash proof means to manually fill the kettle. Trailer kettle refilling should make prudent use of the post operation stuffing of sealant blocks to capitalize on residual heat in conjunction with morning heat-up filling. The capacity of the trailer kettle was selected to be far greater than the size of the truck kettle, so a significant amount of the liquid sealant would remain after the transfer. Sealant kettles are easier to load and far quicker to recover if a mass of hot sealant remains in the kettle.

Hot sealant transfers can be conducted almost any place. The selection of which can be based solely on the preferences of the operator. Standard transfer scenarios are typically based on the specifics of the job and work site. Some issues to consider when establishing a transfer plan include access to boxed sealant supply, fuel, safety, security and timing. The best access to the boxed sealant supply is in the Caltrans maintenance yard, where the sealant is stored and a lift truck may be available to assist in the loading process. The yard is secure and a safe place to operate the trailer kettle. The application truck can return to the yard to conduct sealant transfers where conditions are safe. The roundtrip distance between the yard and the work zone may be far enough apart to create an unacceptable time delay. In this case, the trailer can be towed out to the work zone for transfer on, or near the highway. This method maximizes the sealing application time on the highway with some additional safety risks. After the transfer, the trailer kettle returns to the yard. The transfer trailer can also be operated out on, or near the highway work zone. This type of operation requires more in the way of resources and provides less in safety. The sealant block supply must be transported out to the remote site where fewer resources exist and a secure location must be established in which to operate the equipment. The operator has many options to choose from and to consider when establishing a transfer trailer operational plan and most certainly an effective plan can be developed to match the specifics for every crack-sealing job.

The transfer trailer runs exclusively on propane fuel. Two external eighty seven gallon propane tanks provide the fuel required for a couple days of operation. The trailer kettle can operate on one tank while the other is being refilled. Special propane use quick disconnects connect the tanks together and to the trailer. The propane tanks do not attach physically to the trailer, but instead are placed nearby and are freestanding. For mobile applications, the propane tanks can be placed in the back of the truck towing the trailer. The propane supply line is long enough to reach from the back of the truck to the trailer. The tanks have a lifting loop attached to simplify the lifting and movement of the tanks with a forklift or similar equipment.

The transfer kettle sealant operating temperature is changed by the operator. Under normal operating conditions, it speeds the operation to set the sealant temperature to the application temperature. The sealant transfer flow is far faster at higher temperatures and the sealant can be applied immediately after transferring. The downside to maintaining the transfer at pour temperature is the short sealant lifespan at maximum temperature. Should the transfer for example be delayed and then cancelled a couple of times consecutively then the sealant is in danger of coking and must absolutely be transferred quickly during the next heating cycle. For sealing operations where sealant transfer is not certain, or may be postponed, setting the sealant mass temperature to a lower temperature will extend sealant life. Quantified values equating sealant life to time and temperature are available, but with experience and careful attention small changes to sealant properties can be seen that signal the onset of coking. The best approach is to play it safe and keep the time between maximum temperature transfers to a minimum, or if not than lower the vat temperature.

TTLS Deployment Issues

TTLS Deployment Strategies

The TTLS was designed and built with the intention of being turned over to Caltrans maintenance crews for general deployment and statewide use on California highways after initial testing was completed. The TTLS is a very complex system that could sometimes be understandably beyond the standard capabilities of the operator’s resources to maintain. Past experiences in attempting to maintain deployment of technological advanced equipment in the field has illustrated that equipment support is an essential factor in long-term deployment success. A new concept that will hopefully be further explored with the TTLS deployment will attempt to ensure that Caltrans maintenance operators will have any desired level of support provided for to maintain the machines valuable operation in the field. This will be accomplished by endeavoring to construct a deployment agreement similar to the current equipment commercial rental contract.

Caltrans maintenance stations regularly rent equipment needed for short term use. Equipment like air compressors, generators and lights can be rented when needed. Should the equipment fail, the rental agency is responsible to fix, or replace the equipment without charge and suspends the rental fee while the equipment is not operational. For occasional use equipment, Caltrans maintenance stations pay a premium, but overall find rental costs efficient, due to the savings in equipment maintenance and repair together with the reduction in capitol inventory costs. It may be possible to structure the TTLS deployment in a similar arrangement. Where the rental agency would be AHMCT and the rental fee could fund the operational support of the equipment in the field. This rental approach is presently just a concept, but further development of structure to accomplish this will be explored, as the TTLS field testing and deployment progresses.

DEDICATED OPERATORS

The LCSM was only deployed in Caltrans District 11 and had one of two dedicated operators that would operate the machine throughout the district using local crews to support the sealing operation. The LCSM2 was deployed in multiple districts and overall did not have dedicated operators that followed the machine despite its more complex operational procedure. From this and other experiences it appears that dedicated operators are popular within the district, but are not very practical over long distances. Operator training must be available as the sealing machines travel to different districts, or regions within large districts.

The LCSM2 relied heavily on word of mouth to pass operational instructions along with the equipment to the next district, but often the workers delivering the equipment knew little about how the equipment operated. The TTLS controller was developed to enable an operator with crack sealing experience to operate this equipment with no additional training. The level of automation handles the majority of the machine’s operation by offering the operator choices. The display panel also has help screens that offer more in depth information if desired. The training goes with the equipment.

TTLS TRANSPORT ISSUES

The TTLS concept involves several transport issues related to moving the equipment on, off the highway, and from one maintenance area to the next. During normal TTLS operation, the application truck and sometimes even the transfer trailer will be driven on and off the highway. The application truck especially was designed to be easily configured for highway transport. Whether the application truck is driven a short distance to a local work zone hot and ready to seal, or driven a long distance cold to be delivered to another area of the state, no additional tasks need to be performed to make the truck safe to travel on the highway. In some operations it may be desirable to bring the TTLS trailer out to the work zone for hot sealant transfer. The transfer trailer can be towed by a one and a half ton or larger truck with a trailer air brake system. The propane fuel tanks would be strapped down in the truck bed and the long supply hose with quick connect fittings run down to the trailer. The TTLS trailer can be operated this way in a mobile fashion similar to the application truck. The propane burners must be shut down when towing on open roads and an automatic mobile trailer configuration will be programmed into the user program to operate in a similar fashion to the application truck program.

Since the propane tank on the application truck is permanently attached to the chassis, transporting the propane tank for filling would simply involve driving the truck to a fill station. Few Caltrans maintenance stations have propane fill stations on-site, but propane fill stations are usually nearby. Two propane tanks supply the fuel to the transfer trailer. The supply line and quick connect fitting make connecting the trailer to either or both propane tanks quick and easy. The transfer trailer can operate on one of the propane tanks as the second is being refilled during operation, or both taken for refilling after operation. The propane tanks have a lifting loop to allow for easy lifting by a forklift, or wheel loader with a strap.

Caltrans maintenance crews move equipment between maintenance areas at short to medium distances by delivering the equipment themselves. When the TTLS is transported between Caltrans maintenance stations, at least two workers and a truck would be required to deliver the equipment to the next maintenance yard. One worker drives the applicator truck and the other drives the truck towing the transfer trailer. Both workers then return together in the truck towing the trailer. The applicator truck is not large enough to tow the transfer trailer and even if it were, the second truck would still be required for the workers to return. The two transfer trailer propane tanks are placed in the back of the truck towing the trailer for delivery. To move the TTLS equipment over long distances, a truck transport with a lowboy trailer would be the preferred method. Both the TTLS truck and trailer will fit on a single transport trailer.

TTLS Field Testing

INITIAL TESTING ISSUES

High production automated crack sealing equipment has been in demand for a long time, but despite the high application costs, such equipment is still very much absent from the field. The major reason for this is the nature of hot applied polymer modified sealants, which is the most commonly used type of sealant. The combination of having to heat the sealant to 350 to 400 degrees F to operate the equipment combined with the short life at this temperature, dictates that the sealant must be consistently replaced to avoid becoming a perpetual solid and scrapping the equipment. An example of manufacturer recommendations for sealant application life is included in Appendix C. For the TTLS, which is designed to apply enormous quantities of short-lived sealant, this means that testing procedures must include plans to regularly discharge and replace sealant. Simply dumping hundreds of gallons of 400 degree F sealant is very problematic. The easiest approach is to conduct the bulk of the initial TTLS testing where the sealant can run out sealing longitudinal cracks. Since major highways are the typical place to find miles of straight longitudinal cracks, prototype crack sealing equipment cannot realistically ever be initially tested. This difficultly with testing stunts innovation and scuttles all but the most persistent of research efforts.

The TTLS initial testing program is in all actuality nothing less than limited deployment to Caltrans of untested research equipment. Crack sealing equipment takes hours to make ready every time it is used. Additional hours are invested in establishing a highway lane closure to access longitudinal crack. If equipment problems prevent crack from being sealed, precious time is wasted and interest wanes with Caltrans maintenance crews. In addition, a series of seemingly small problems that sequentially halt the sealing operation can easily result in the "coking" of sealant in the kettle. Large investments into expensive crack sealing equipment are always at this risk and can be quickly and completely lost. Adding a large number of untested research systems to a kettle operation that can only be tested on the highway is certainly a high-risk research endeavor.

The initial heat-up of both TTLS systems were conducted off-highway to verify basic operational abilities. The burners can be run and the heat transfer oil in the kettles can be heated repeatedly if necessary, but once sealant is loaded the short sealant life span at operating temperature becomes a major factor to be considered. With sealant in the kettle every heating should include a plan to discharge, or add more fresh sealant. Typically, during initial system tests with sealant, the kettle sealant level is run low. Therefore, should problems occur fresh sealant could be added even if sealant cannot be discharged. Only after the proper operation of all systems are verified is the sealant level brought to full in order to conduct normal highway operational testing and evaluation.

Both the TTLS truck and transfer trailer rely on PLC control to operate this equipment. Several versions of the operational program for each machine were developed to assist in the initial testing phase. An initial set-up program was used which allowed for direct operation of every output and individual displays for each input on the user panel. The set-up program was a valuable tool for verifying and troubleshooting sensor, hydraulic and electrical issues. With electrical integration completed, a second program, the first and most basic in an ever-evolving string of user programs, was written. The basic user program grouped the inputs and outputs into the logical procedural steps that would be required to operate the machine. The basic program contained only the bare automation essentials necessary to operate all machine functions, but this program would also serve as the framework that will eventually evolve into a fully automated user program.

INITIAL FIELD TESTING PLAN

The TTLS transfer trailer's only function is to transfer hot sealant to the truck for application. Therefore, the application truck must first be able to apply sealant before the transfer trailer can be realistically tested. This is why the TTLS application truck was tested first even though the transfer trailer fabrication was first to be completed. The TTLS truck is fully self-contained and is capable of stand-alone sealant heating and application operations. Sealant blocks are simply loaded into the top of the truck kettle and heated when manually filling the truck kettle. A series of three off-highway field tests were conducted before sealant was flowing into the sealing shoe and successfully applying a band of sealant. The test road did not contain any longitudinal cracks to fill, so the next step was to find highway cracks for the TTLS application truck to seal.

Initial testing of the TTLS transfer trailer is more conducive to off-highway testing, since the machine would generally be operated off-highway in normal use. The difficulty in testing the TTLS trailer is again in the nature and amount of the sealant the machine is designed to handle. A plan to dispense, or add significant amounts of sealant must be considered every time the transfer trailer is heated. This typically means the TTLS truck would be conducting simultaneous highway crack sealing operations and require a large hot sealant supply that the transfer trailer could supply. To simplify initial transfer trailer testing, a two step process was utilized. The application truck conducts highway longitudinal crack sealing operations until emptied. At later date, only the transfer trailer is heated and the hot sealant transfer conducted with the truck kettle not heated. The two-step initial testing process is a simpler operation, since only one machine is operating at a time and it minimizes the sealant life risk should malfunctions occur during the initial testing stage. Once confidence is established in the reliability of both machines, simultaneous operations can be conducted to fully evaluate the full high production potential of the TTLS on the highway.

GENERAL ROAD TESTING TASKS

The TTLS concept is original and unlike any other equipment in the field. Assumptions were the basis for many design issues pertaining to the operation of these machines. Experimentation in the initial testing phase would be required to complete the development of the TTLS project. Vehicle weights were one of these assumptions. Working only from approximate estimates of what the custom kettles might weight, the truck chassis was selected, weight distributions established and axle weights determined. Only after the prototypes were tested could the actual machine weights be measured. Vehicle weight capacities are based on maximum loaded weights, therefore the kettles had to be completely filled with sealant and weighed to determine the actual axle weights. The kettles are not completely filled until near the end of the initial testing phase, so the compliance to axle weight capacities would take place just prior to deployment. Should the kettle weight be greater than expected, axle capacities were selected to be greater than expected to account for the unknown weights in the case of the transfer trailer. In the case of the truck chassis, the next step higher in axle capacities necessitated a larger than acceptable step up in truck chassis size. To provide for some leeway in truck axle capacities, only essential equipment was initially loaded onto the chassis. Additional equipment such as crack cleaning, trailer hitch and systems to aid moving lane closure operations were omitted until the actual truck axle weights could be measured.

Programming issues account for the majority of road test tasks. The basic operational program developed for both machines was only intended to establish basic machine operation. Initial heat-up tests required minor program modifications to produce the desired operational characteristics. Both machines shared many common programming features, so many of the required program changes discovered on one machine could be similarly changed on the other, reducing development time. Once basic program control was achieved on each machine, field testing could begin. Operating these machines with the basic program, requires an extensive knowledge of the equipment and was not intended for general use. Throughout the initial testing phase additional programming features would be added to the basic program as these features surfaced. The end of the initial road test phase would coincide with the development of a simplified user program allowing for a minimum of user training to experiment with limited Caltrans deployment duty.

APPLICATION TRUCK INITIAL ROAD TESTING ISSUES

Since the bulk of the initial TTLS application truck testing would occur on and with Caltrans maintenance crews, Caltrans safety personnel were contacted to verify that the application would meet Caltrans equipment safety operational guidelines. Representatives from several Caltrans divisions reviewed the TTLS truck and recommended safety improvements. Features including hand rails, machine guards and material improvements were installed on the machine to mitigate all suggested potential safety hazards before road testing began. The larger issue of final vehicle certification was left to be resolved in the future should ownership of the TTLS prototypes ever be completely turned over to Caltrans.

During the initial road testing phase, the operation of the application truck on the highway would be the sole responsibility of the development staff. Caltrans maintenance workers would be required to support the crack sealing operation, but until further development of the user program was completed, general operator training would not be practical. Highway testing operations would only require Caltrans maintenance workers to operate the lane closure operations, while the responsibility to prepare and operate the application truck on the highway belonged to research personnel. Given a desired highway sealing start time target, the truck kettle was heated off-site and typically delivered to the work zone ready to apply sealant.

APPLICATION TRUCK TESTING RESULTS

Only after the truck fabrication was completed could the kettle be heated. The first heating tests were performed without sealant. Sealant was added to the kettle in the next heating test. Subsequent heating tests with the application kettle now filled with sealant, provided the first opportunity to evaluate the kettle heating capabilities. Heating tests of the TTLS application truck right from the start showed ominous signs of heating time problems. Commonly available sealant kettles require two to three hours to heat from ambient to sealant pour temperature. The Cleasby mfg. Co. sealant kettle purchased and mounted on the TTLS application truck was requiring three to four times longer than normal to heat-up. The most important and fundamental objective of the TTLS concept was to develop an ample hot sealant supply for the high speed longitudinal application equipment, which has always been the limiting factor for seal production on the highway. In order to test if the TTLS concept is a valid method of creating this ample hot sealant supply, it was essential that the TTLS kettles possess the fastest heating characteristics available. Once it was determined the TTLS Cleasby kettles possessed dramatically less than normal heating characteristics, it became immediately clear that the effort to ultimately deploy the TTLS equipment in the field with Caltrans had become unattainable. Equipment testing did continue and the focus had changed to evaluation and the development of methods to mitigate this problem.

Heat-up times for the application truck kettle dictate the required process starting time for the machine to reach operational temperature by the target sealing start time. A typical Caltrans maintenance crew sealing operation is deployed on the highway at 10:00am after the morning traffic subsides. For the TTLS application truck to be ready to seal at this time, the truck kettle heating had to begin at 2:00am. When heating a kettle with a normal heat-up characteristic, the crew begins the heating at 7:00am which is a common starting time for Caltrans maintenance workers. Obviously, it is not reasonable to require an operator to endure such a long heat-up time. During the several initial highway tests that were conducted with the application truck, AHMCT deployment support personnel were given 24 hour access to the maintenance yard in which to start the kettle at 2:00am. The application truck kettle would be heated in the yard and driven out on the highway ready for sealing operations at the required 10:00am start time. In addition to this unreasonable start time, the long kettle heat-up times reduced the useful life of the sealant, so much so, that a single kettle heat-up cycles without replacing the sealant, typically by applying most of the sealant in the tank, was producing sealant coking and carbon ball problems.

Other than the previously discussed kettle issues, the TTLS application truck systems are completed and are currently operating correctly. The application speed and production capabilities have proven in field testing to be exceptional. The establishment of the in-cab operator control makes the operation of the machine almost effortless and provides for an unprecedented level of control. Conducting sealing operations in a moving lane closure has been straightforward and has greatly reduced the size of the effort needed to conduct sealing operations on the highway. The TTLS strategy of running the sealing operation without having to add sealant blocks on the highway, also contributed greatly to simplifying sealing operations. All systems are operating as designed and machine operational issues are a complete success. During field testing experienced Caltrans maintenance crews were very impressed with the machines function and have commented that the design had been carefully though through. Unfortunately, kettle deficiencies are the only obstacle standing in the way of a very successful and productive machine field deployment to Caltrans.

TESTING RESULTS COMMON TO TRUCK AND TRAILER

Caltrans requested that the TTLS operate on green fuels, so a switch from the typical diesel fuel to the less efficient propane was made. Running the TTLS on propane fuel has many disadvantages, but the main problem is related to temperature issues. Crack sealing operations are ideally conducted in the coldest seasons when the pavement cracks are the widest. When operating propane vapor systems in cold weather, propane tank freezing becomes an issue. Initial application truck tests were hindered by issues related to propane tank freezing. Two solutions are readily available, either heat the propane tanks, or develop a liquid withdraw burner. In an effort to complete initial field testing of the application truck, an electrical heating pad was attached to the propane tank powered by the on-board AC generator to prevent tank freezing. The use of the heating pad was certainly successful as a temporary solution, but ultimately may not prove to be the final solution.

Cold weather operation does provide a little assistance with another commonly encountered problem, the maximum operating temperature specification of the touchscreen user panels are within the range of normal TTLS operation on warm days. Unfortunately, as the panel approaches higher temperatures, the screen brightness starts to fade and become difficult to read. Also the visibility of these user screens can be quite limited in certain daylight situations and are altogether unreadable in direct sunlight. The user panel on the application truck is in the cab and can typically be shaded. The panel on the trailer has a hood that can be flipped down to provide shade. Both of these effects combined have made TTLS testing difficult at times.

HIGHWAY OPERATIONAL ISSUES

The TTLS application truck was designed to have the unprecedented ability to conduct longitudinal crack sealing operations in a moving lane closure. To accomplish this feat was to further reduce the costs of a sealing operation by eliminating the cost of establishing a fixed lane closure. In addition, moving lane closure operations present less of an impact on traffic and enable the sealing of longitudinal cracks between lanes which are often unreachable with fixed temporary traffic closures. Many of the TTLS initial highway tests were conducted in moving closures, which provided the opportunity to test and evaluate some purely deployment related machine issues.

In a moving lane closure the trailing traffic control vehicles and general traffic can come in contact with the freshly applied sealant. Hot sealant has a greater desire to stick to rubber tires than the pavement. This pulls the sealant off the road and fouls the vehicles tires. For the TTLS testing, a release agent was sprayed on the fresh sealant in an attempt to mitigate this problem. A spray system was installed and integrated on the application truck to automatically spray when sealing. Initially a fine mist of plain water was tested as a release agent, but failed to produce the desired effect. Next a commercially available release agent designed for this specific use was tested. The cost of the product seemed fairly high, so the product was first tested mixed half with water. In this state the release was minimally effective. It was apparent though that the TTLS release spraying equipment, combined with some kind of release product would ultimately be effective, but it would be better left up to the operator to choose their product and mixture of preference.

The sealing shoe extends almost two feet from the side of the application truck, providing for an unobstructed view of the sealing shoe. Often time longitudinal sealing operations are conducted on the boundary between the closed lane and live traffic lanes. The potential for a vehicle traveling in the live lane and hitting the sealing shoe must be considered. Caltrans requested that a means of deploying a visual barrier from the side of the application truck during such operations needed to be added to reduce the risk of hits. An easily deployable plastic barrier strip device was installed on the truck rear bumper to provide a substantial visible barrier for traffic to avoid, but if hit, would swing away minimizing any damage.

Crack cleaning procedures were often discussed with Caltrans maintenance personnel during initial TTLS highway tests. It was agreed that major cleaning efforts should be conducted prior to the day of the sealing operation for several reasons. It is equally important to perform a light blow out of the longitudinal crack immediately ahead of the sealing application. Removing any light dust or debris that has settled into the crack since the heavy cleaning could significantly improve seal quality. Typically a trailer air compressor is rented for the task, so provisions for an on-board air compressor will not be necessary. Instead a medium duty trailer hitch should be added to the application truck to provide the ability to tow an air compressor and provisions should be made to enable the air hose to be easily hung on the truck. An adjustable blast nozzle device with a generic connection should be incorporated with the new applicator design so to provide a means to integrate cleaning in with sealing operations.

APPLICATION TRUCK INITIAL ROAD TEST #1

In April 2005 the TTLS application was first operated on the highway with Caltrans District 3 Maintenance support on Highway 113 in Woodland. The sealing operation was conducted in a number one lane closure sealing a wide longitudinal joint crack between the number one and two lanes. The application truck was operated alone without the transfer trailer and loaded directly by hand with boxed sealant. Approximately two to three hundred gallons of sealant was applied in a couple of hours sealing about a half mile of longitudinal crack. The operation was terminated prior to reaching the planned distance due primarily to sealing shoe functional issues resulting in less than acceptable seal appearance. Modifications have been completed on the sealing shoe mounting that were not available in the field and the application truck was made ready for continued testing. The truck kettle was left empty to facilitate the next step in the initial testing operation, hot sealant transfer.

APPLICATION TRUCK INITIAL ROAD TEST #2

In September 2005 the TTLS application was next operated on the highway with Caltrans District 4 Maintenance support on Highway 4 in Antioch. Truck kettle heating began at 2:00am in the maintenance yard and highway sealing operations were started at approximately 11:00am. The kettle was still not fully heated, but the kettle sealant temperature appeared to have leveled off so the sealing operation was started. Approximately three hundred gallons of sealant was applied in a little over a couple of hours on a longitudinal shoulder crack. A large unmelted mass of sealant remained in the kettle and was subsequently heated and pumped out into a waste barrel upon returning to the maintenance yard. The operation was conducted with a moving lane closure with the TTLS truck driven along the shoulder taking the slow lane as a safety buffer. An equipment problem caused some problems that were temporarily overcome in order to apply the sealant, but repairs would be required before testing could continue. The TTLS truck was returned to AHMCT for the repairs. The applicator bar and one of the bypass valves would have to be rebuilt.

APPLICATION TRUCK INITIAL ROAD TEST #3

In December 2005 the TTLS application was returned to highway testing operations again on Highway 4 in Antioch with District 4 Maintenance support. Truck kettle heating began at 2:00am and highway sealing operations were started at approximately 11:00am. The kettle was still not fully heated, but the sealing operation was started regardless. The sealing operation was conducted in a moving lane closure with the application truck running in the slow lane sealing the shoulder joint. A release agent was sprayed on the fresh sealant to reduce the potential of tracking from the vehicles involved. In just over an hour approximately three hundred gallons of sealant was applied, until all melted sealant was pumped out of the kettle. Another 50, or so gallons remained in the kettle unheated. So the truck kettle was further heated for about an hour on the highway to enable the remaining sealant to melt. A short sealing operation followed to completely empty the kettle. Approximately a mile and a half of longitudinal shoulder crack was sealed during this test.

TRANSFER TRAILER INITIAL TESTING

Tests of the TTLS transfer trailer were squeezed in between highway tests with the TTLS application truck whenever possible. Since the transfer trailer only functions as a hot sealant supply, a place to transfer the hot sealant has to be provided before attempting to heat the kettle. The application truck kettle would normally be refilled immediately when emptied utilizing the residual oil jacket heat to assist with sealant melting and reducing the potential for coking. To provide the opportunity to test the transfer abilities of the transfer trailer, the truck tank was purposely left empty after each highway test.

Transfer trailer testing would be initially conducted when the application truck is cold with the goal of refilling it with a trailer hot sealant transfer. The filling spout on the application truck was designed to allow for the possibility of cold transfers. The transfer trailer would be towed to an appropriate site for heating away from the research laboratory. A medium duty truck with air brake trailer brake system was needed to provide a means to tow the trailer on the road. Caltrans Equipment service center loaned this project such a vehicle to be used on a short-term basis in order to tow the transfer trailer as needed for initial testing. The two propane cylinders required to fuel the operation of the transfer trailer were placed on the truck flat bed with quick connect hoses connecting both tanks to the trailer. The trailer kettle was then mobile, operational and ready for testing.

The transfer trailer was heated for the first time in May 2005 at an off highway location. The kettle heat transfer oil reached set point temperature in less than two hours and boxed sealant was added to fill the kettle. Three hours into the first test, a large oil leak was discovered. Upon closer inspection, the source was determined to be a leak in the heat transfer jacket. The test was immediately terminated and the transfer trailer was returned to the manufacturer for repair. The manufacturer determined the cause to be their faulty welds around both burner tubes. The repair was a lengthy process requiring several repairs only to discover more leaks upon sequent heating attempts. Eventually it appears that the leaks were repaired, but while in the process of successive heating attempts, the manufacturer created a large carbon ball of coked sealant in the vat preventing normal operation and threatening to scrap the machine if it was not able to be removed. A risky heating operation was conducted in an attempt to melt the carbon ball and pump it out of the kettle. The transfer kettle was heated higher than the safe temperature range to try and melt the carbon ball so it could be pumped out of the kettle. This operation was successful and the kettle now seems to be operating normally and is on track again for additional testing and evaluation operations. Further field testing of the TTLS transfer trailer is currently on hold pending the resolution of heating deficiency of the application truck.

TTLS Final Recommendations

SEALANT KETTLE REPLACEMENT

Ultimately the final measure of the effectiveness of the TTLS design will be based predominantly on highway sealing production data. Half measures and minor improvements in the heating characteristics of the existing application truck kettle could eventually undermine the project entirely. It is therefore recommended that the application truck kettle be completely replaced. Kettle replacement will also solve a significant number of smaller application truck operational issues that are either directly, or indirectly caused by truck kettle heating deficiencies. Since the truck kettle is fairly self-contained and utilizes a minimal chassis mounting, swapping-out the kettle is a viable option. The kettle to chassis mounting is similar and most of the electrical and control systems are reusable.

The transfer trailer kettle heat up times based on limited testing also appear to be longer than expected, but currently don't seem to be quite as poor as the truck kettle. Also the fast heating and operational abilities of the transfer trailer are far less critical than the application truck to overall TTLS performance and production. The transfer trailer heating and sealant recovery performance is the key factor in achieving multiple sealant transfers per day. Ideally replacing both kettles would be optimum, but replacing the trailer kettle would require an entirely new machine be built. At this time, the advantages of sticking with the current transfer trailer outweigh the costs and delay caused by replacement. In addition, by upgrading the application truck heating abilities, procedures can be instituted to shift more of the duties to the fast heating application truck kettle and away from trailer kettle.

APPLICATION WAND ADDITION

There is a growing criticism within Caltrans that even though longitudinal sealing machines have demonstrated dramatic increases of seal production rates, they are limited to sealing only longitudinal cracks which reduces the overall usefulness of the machine. Therefore, Caltrans maintenance has requested that a standard sealant hose and wand assembly be added to the application truck. Adding the sealant application hose to the truck would require relatively minor changes to the existing machine's user program, sensors and controls. The sealant hose could be used in a manual crack sealing operation to enable the application to be utilized to seal all types of cracks on the highway. Since the longitudinal sealing process is a continuous process that can be conducted in a moving lane closure and the standard in-lane sealing operation is a stop and go process that definitely necessitates a fixed temporary lane closure, both sealing operations would not take place simultaneously, but the same machine could support either sealing operation separately. Furthermore, application of new TTLS features to the hand sealing operation can provide certain safety, production and cost benefits as well.

TTLS Application Truck Upgrades

The replacement of the application truck sealant kettle and the addition of a sealant hose represent the two major truck upgrades and will necessitate the rebuilding of many of the associated subsystems. In this process, several smaller issues and improvements will be incorporated in the new machine to further improve the operation and production abilities of the machine. Directly related to the kettle swap-out will be the rebuilding of the sealant passage possibly moving the connection junction to a different spot which will be more advantageous to sealant hose operation. A new truck bed layout may enable the relocation of the propane tank to a more protected position. Other upgrades will be based on Caltrans Maintenance crew requests solicited during field tests. These upgrades are generally linked to deployment related issues, such as the addition of a trailer hitch to enable the towing of an optional air compressor for crack cleaning operations. While other changes were still based on operational improvements that surfaced during operational testing, these upgrades will improve the machine’s capabilities such as adding a more powerful gasoline engine to increase hydraulic power and upgrading the user panel with newer brighter version. The kettle burner will most likely be switched to a Red Dragon Inc. liquid propane kettle burner in an effort to mitigate the propane tank freezing issue. Several components and circuits will have to altered to fit the new kettle, but overall application truck upgrades seem to represent fairly straightforward tasks.

Sealzall Conversion Tasks

The addition of a sealant hose to the TTLS application truck to provide for manual crack sealing capabilities should be considered to be more than an just an upgrade to the application truck. With the ability to seal all types of cracks on the highway, the new machine would require a name change. The new machine should be called the Sealzall machine because it supports the sealing of all types of cracks. The addition of the sealant hose should be merged with a redesign of the current longitudinal application bar to produce a dual use component thereby reducing complexity and costs. An altogether new design would have to be developed, but the complexity of the application hardware will be greatly reduced. The hose addition will have a minimal impact on the current state of the electrical, mechanical and control systems. Hose operation controls will have to be developed and added to the user program, but the basic machine functional control changes very little.

The list of specific tasks that need to be developed to convert the longitudinal only TTLS application truck into the proposed Sealzall sealing machine is surprisingly short. The hose itself should be a commercially available heated hose such as a product sold by Cimline Inc. which is 20ft long. This unusually long length combined with a custom designed Sealzall boom support would provide for a large work area in front of the truck. The sealant hose addition will necessitate the redesign of a longitudinal sealing shoe mechanism to be used only when conducting longitudinal sealing operations. The sealant hose mounting will require the development of a sealant hose reel and heated sealant passage connection. To enable the sealant hose to recirculate sealant back into the kettle, a hardware connection to the kettle will be developed. The last significant improvement will be the addition of a trailer hitch to the truck to enable an air compressor to be towed for crack cleaning purposes.

PROPOSED TTLS TRANSFER TRAILER UPGRADES

Only minor improvements are being recommended to the transfer trailer at this time. Further field testing will be required to accurately determine the capabilities of the current machine and how well it is able to support the application truck in the field. These upgrades will improve machine operational issues. As with the application truck, an effort to switch to Red Dragon Inc. liquid propane burners will be attempted. Currently the dual propane supply tanks sit separately. A skid needs to be developed for these tanks to simplify their use, storage and transportation in connection with the transfer trailer operations. Lastly, a newer version of the display panel is available which would be easier to read and have a higher operational temperature limit. The panel replacement should be done and is a simple change which will not require any programming changes. Display panel over heating was a problem encountered on both machines during field testing, which was especially problematic on the trailer. The addition of enclosure fans combined with panel upgrades should solve this problem. If panel heating problems arise again on the trailer, the display panel may have to be relocated to a separate enclosure to help lower panel operating temperatures.

Appendices

APPENDIX A

Caltrans Deployment Evaluation Longitudinal Crack Sealing Machine
Courtney LCSM2 Report 2002

Project Title: Longitudinal Crack Sealing Machine (LCSM)

Customer: Division of Maintenance

Sponsor: Division of Maintenance

Champions: DDD's for D3, D4, D11

Project Overview:

The Longitudinal Crack Sealing Machine (LCSM) was developed to automate sealing continuous longitudinal cracks, such as those that occur between a concrete lane and asphalt shoulders.

The LCSM enables a highway worker to seal longitudinal pavement cracks and joints with hot applied sealant from the safety of the truck cab. No longer do workers have to be exposed to direct traffic in longitudinal sealing operations as in the traditional manual application procedure. The driver controls the entire sealing process from within the truck cab while a support worker is typically utilized to load the sealant blocks into the kettle. Use of the LCSM also dramatically increases seal production rate, primarily by eliminating the strenuous nature of the operation.

The LCSM driver remotely deploys the application head to the pavement, steers the truck along the crack, controls sealing speed with the accelerator petal, and remotely controls the sealant flow with a hand controller. The shoe pulls along a reservoir of sealant that overcomes the random change in crack size. A display screen in the cab relays machine status information to the driver.

The Longitudinal Crack Sealing Machine has been in operation for almost three years. This field experience revealed a deficiency caused by the increased production rate: the LCSM could not melt sealant fast enough to keep up with the increased speed of the operation. The Division of Equipment responded to the sealant problems by developing a double-kettle trailer. Using two kettles expanded the supply of hot sealant; after all sealant is applied in the front melter, material is then replenished from the rear melter.

The LCSM has been operated in four different Caltrans maintenance districts, but has primarily been operated in District 11 and is currently deployed there. The District 11, Chula Vista Travelway Crew has reported some cost data when using the LCSM vs. Hand Applied Operation.

Cost Comparison Data 10/02/03

Distance Compared: 32 miles along Interstate-5

	LCSM	Hand Applied
Number of employees	3	4
Average miles per day	3.5	0.8
Work days	9	40
Bare rate cost	**$4,017**	**$23,820**
Closures	NO	YES
Employees on foot	NO	YES

- LCSM

In 17 days, 62 miles of AC/PCC joint line was sealed on Routes 5, 52, and 125.

- Hand Applied Method

The same amount of miles sealed would have required 77.5 days, 78 lane closures, and 465 hours of exposure of employees on foot to traffic.

Current Stage of Project:

How often is the LCSM used? The LCSM was put into service in March 2001. During the time period of March 2001 to March 2004 there is a total of 509 workdays. Of those days, there has been only 183 confirmed days that time was charged to the LCSM in our database. 157 days were charged by maintenance for sealing cracks, 9 days down in the field, 13 days for preparation work and 3 days for relocation. The Equipment Shop charged 79 days for preventative maintenance. The other 247 days the LCSM was idle or down in the shop. I could not confirm down time from the shop.

MMS DATA: 02/08/01 to 06/30/02

- 46 days charged to equipment in District 06; 5 days of preparation, 1 day to move the LCSM, 3 days down in the shop, and 37 work days with 153 lane miles of production.
- Average daily production was 4.5 lane miles and 0.5 tons of material. No cost data is available.

- 51.5 days charged in MMS in District 11; 5.5 days of preparation, 1 day to move the LCSM, 3.5 days down in the shop, and 28 days with no material charged to the work day.
- Average daily production was 2.3 lane miles and no reliable data for tons of material. No cost data is available.

IMMS DATA: 07/01/02 to 03/15/04

(83 days were charged to equipment).
LCSM has had twelve work orders completed, 83 days that the unit was worked. 16 of the days no material was charged but 8 lane miles production was charged, five days with no production, i.e. (machine preparation or transportation days) and one day use in a storm water BMP. 55 days were charged for sealing cracks with 105 lane miles of production and 37 tons of material used.

IMMS Comparison Data:

- Average daily production 2 lane miles.
- Average daily equipment usage 10 hours
- Average daily material usage 0.67 tons
- Average daily cost $1776.00
- Average cost per lane mile $930.00

Equipment Repair and Rental Rate Data:

- 79 days down for preventative maintenance, loss of use was $4,607.00.
- 520 hours labor, a cost of $20,060.00.
- 65 days down for repairs, loss of use $3,791.00
- Parts cost $9,270.00.
- Kettle cost is $25.91 a day, $9,457.15 a year.
- Tow vehicle cost is $32.41 a day, $11,829.65 a year
- LCSM cost is $58.32 a day, $21,286.80 a year
- Three years service was $63,860.40 for 157 days of sealing cracks equals $406.75 rental for each day used.

Injuries that may have been avoided:

- There have been a total of 76 injuries in the last 10 years associated with rubber crack sealing.
- 27 employee injuries resulted from applying rubberized product on foot.
- 12 employee injuries resulted from loading material.
- 39 employee injuries reported that were not related to just rubberized crack sealing.

Crack Sealing/Filling:

- Longitudinal Joints are normally sealed during construction and resealed as needed throughout the life of the pavement.

Longitudinal Cold Joint Cracks

Crack sealing and filling prevent the intrusion of water and incompressible materials into cracks. The methods vary in the amount of crack preparation required and the types of sealant materials that are used.

Crack sealing:
Crack sealing is the placement of materials into working cracks. Crack sealing requires thorough crack preparation and often requires the use of specialized high quality materials placed either into or above working cracks to prevent the intrusion of water and incompressible materials. Crack sealing is generally considered to be a longer-term treatment than crack filling. Due to the moving nature of working cracks a suitable crack sealant must be capable of:

- Remaining adhered to the walls of the crack,
- Elongating to the maximum opening of the crack and recovering to the original dimensions without rupture,
- Expanding and contracting over a range of service temperatures without rupture or de-lamination from the crack walls, and
- Resisting abrasion and damage caused by traffic.

Crack Filling:
Crack filling is the placement of materials into non-working or low movement cracks to reduce infiltration of water and incompressible materials into the crack. Crack filling typically involves less crack preparation than sealing. Performance requirements may be lower for the filler materials and it is often considered a short-term treatment to help hold the pavement together between major maintenance operations or until a scheduled rehabilitation activity. Crack filling is for active or non-active cracks created by aging of the binder. Such cracks are not completely inactive and require some flexible characteristics. A suitable filler material must be capable of:

- Remaining attached to the walls of the crack,
- Possessing some elasticity, and
- Resisting abrasion and damage caused by traffic.

TREATMENT PERFORMANCE

The performance life of a treatment is affected based on the amount of crack preparation and the type of material used. It has been found that depending on the amount of preparation and material selection, crack sealants can provide up to 9 years of service and fillers up to 8 years of service. In California, over-banded treatments have contributed to poor ride, ride noise and poor surface appearance and are not recommended for use unless it has been squeegeed flush to the surface of the road. It should not be placed more than 12.5mm (1/2 inch) wider than the width of the crack (on both sides of the crack). Emulsions or asphalt materials placed in a flush configuration in un-routed cracks can provide 2 to 4 years of service while hot applied rubber and fiber modified asphalt fillers placed in flush or over-banded configurations can provide 6 to 8 years of service. Several methods exist for evaluating a treatment's performance. One method is based on determining a treatment's effectiveness. Treatment effectiveness is the success of the treatment measured as a percentage of the total treatment that has not failed (4). In order to determine the condition of a treatment, visual inspections of the treated areas are required. Inspections for treatment failure should be carried out once per year.

Treatment Failures

Treatment failures can be attributed to improper treatment selection, improper material selection, poor workmanship, and improper application or lack of post-treatments. Common treatment failures include:

- Adhesion loss: The sealant does not adhere to the sides or bottom of the crack.
- Cohesion loss: The sealant fails in tension by tearing.
- Potholes: The crack is not completely sealed, allowing water into the pavement. Continued deterioration leads to pumping and pothole formation.
- Spalls: The edges of the crack break away as a result of poor routing or sawing.
- Pull-on: The sealant is pulled out of the crack by tire action.

Treatment Effectiveness

The first step in determining a treatment's effectiveness is establishing how much of the treatment has failed in relation to the total length of treatment applied (% failure). Once the amount of treatment failure is determined, the treatment's effectiveness can be calculated using the following expression.

Effectiveness = 100 - % failure

Where: % Failure = 100 X [Length of Failed Treatment / Total Length of Treatment]

Cost Effectiveness

The cost effectiveness of a treatment can be determined readily once the treatment effectiveness has been determined. Cost effectiveness is the total cost of a treatment divided by its effectiveness. Cost effectiveness may be converted into an annual cost by dividing the cost effectiveness by the number of years required to reach 50% effectiveness.

MATERIALS

Crack sealing and filling material specifications for Caltrans fall under SSP 37-400 (7), 41-200 (8),51-740 (9) and Standard Specifications Section 94 (10).

Materials for Crack Sealing

Crack sealing materials are designed to adhere to the walls of the crack, stretch with the movement of the crack over the range of conditions and loads associated with the crack location, and resist abrasion and damage caused by traffic. For sealing working cracks, the preferred sealant is usually elastomeric. This means the sealant has a low modulus of elasticity and will stretch easily and to high elongations (usually around 10 times its non-strained dimensions) without fracture. Such sealants also recover over time to close to their original dimensions. The sealants are usually applied at elevated temperatures

SELECTING THE APPROPRIATE PLACEMENTMETHOD

The appropriate placement method should be based on the governing considerations of the project. Governing project considerations include:

- Type and extent of the sealing or filling operation,
- Traffic conditions,
- Crack characteristics,
- Material requirements,
- Desired performance (expectations),
- Aesthetics, and
- Cost.

Cleaning and Drying

Debris left in a crack, resulting from sawing, routing, or pavement use will affect the adhesion of the sealant or filler. Debris also contaminates the sealing or filling material and reduces cohesion. Reduced adhesion or cohesion normally results in early failures. To avoid these contamination-related failures, sawed or routed cracks must be cleaned prior to being treated. Several cleaning methods can be used, including:

- Air blasting,
- Hot air blasting,
- Sand blasting, and
- Wire brushing.

Air blasting involves directing a concentrated stream of air into the crack or joint to blow it clean. Air blasting equipment is effective and efficient for cleaning cracks. Air blasting is not efficient for drying cracks. If a crack requires drying, hot air blasting should be used. Air pressure should be a minimum of 670 kPa (97 psi) with a flow of 0.07 m3/s (2.5 ft3/s). Air blasting equipment must be equipped with moisture and oil traps. Hot air blasting is done using a hot compressed air heat lance. While cleaning and drying the crack, hot air blasting also promotes enhanced bonding associated with the crack edges being warmed. Care must be taken to ensure that the pavement is not overheated or heated for excessive periods of time as this will result in unnecessary hardening of the asphalt binder in the pavement adjacent to the crack.

Sand blasting involves directing a stream of sand entrained in compressed air into the crack. The abrasive nature of the sand cleans the crack or joint. Sandblasting, which is used for cleaning cracks in PCC pavements by many states, is an effective treatment. However, sandblasting is messy and typically requires a two-phase operation. The first operation is cleaning the joint surface; the second cleans the sand from the joint and its surroundings. On new PCC pavements, sand blasting is required to clean the surface prior to applying the sealant.

Wire brushing or brooming involves the use of a wire broom stock or stiff standard broom to brush out the crack or joint. Wire brushing can be an effective cleaning method. Wire brushing may be done manually or using power driven brushes. Figure 18 illustrates the manual crack cleaning method using a broom

Project Review:

Where and when to use it?

The Longitudinal Crack Sealing Machine is limited to one type of operation. Ideally it would be used for sealing newly constructed projects, and/ or in conditions where debris has not enter into the joints. As it is now the crews use it to seal cracks that have and have not been cleaned which leads us to believe that this is not the best practice for crack sealing. The purpose of joint sealant is to minimize infiltration of surface water and debris from entering into the joints. The LCSM is limited to joint sealing only, there fore you must return if you need to seal random cracks causing a delay to traffic a second time.

Method of Crack Sealing/Filling:

- Determine crew size?
- Need to determine the best recommended Longitudinal Joint sealing method.

Do we need more LCSM?

- **Pro**
- Field Maintenance crews like the concept that they are not exposed to traffic.
- Do not have to breathe the fumes of the product and /or have the exposure to the hot product
  via the wand or squeegee.
- They like having the ability for more production and not having the lane closures to deal with.
- **Cons**
- Machine is not being used
- Maintenance does not like a lot of prep work to start the LCSM.
- The LCSM will not keep up with output, and they don’t like the way they have to load the product into the kettles.
- They do not like the lack of training that they receive before they operate it.
- They do not like not having a way to blow out the cracks as part of the operation.
- Have to come back to do random cracks.

Changes

- A way to blow out the cracks as part of the operation.
- A better heating system with maybe more BTU to heat the product faster.
- A change in the way material is loaded.
- One fuel source (one fuel tank for all).
- Better training when they use the equipment.
- A simpler design so it is more reliable.
- A design that will keep up with output.

How much do we use the LCSM?

Looking at the LCSM usage for the past three years, this machine has only been used 157 days for sealing cracks which is only 31% of the totals days it has been available for operation. It has
only sealed 377 lane miles of cracks out of 16,299 lane miles of joint cracks, less than 2% of the joints.

Need to develop a evaluation plan:

Treatment Effectiveness

The first step in determining a treatment's effectiveness is establishing how much of the treatment has failed in relation to the total length of treatment applied (% failure). Once the amount of treatment failure is determined, the treatment's effectiveness can be calculated using the following expression:
Effectiveness = 100 - % failure
Where: % Failure = 100 X [Length of Failed Treatment / Total Length of Treatment]

Have the District LOS Coordinators review the locations that have been sealed using a standard form with the notation of clean or not cleaned cracked.

Cost Effectiveness

The cost effectiveness of a treatment can be determined readily once the treatment effectiveness has been determined. Cost effectiveness is the total cost of a treatment divided by its effectiveness. Cost effectiveness may be converted into an annual cost by dividing the cost effectiveness by the number of years required to reach 50% effectiveness.

Tracking cost:

Have IMMS assign a project number to LCSM operation and have supervisors charge each day's labor, equipment, and material to one work order each day.

Better Marketing:

- LCSM assigned to HQ Equipment pool and HQ pay the rental cost.
- HQ Maintenance pays for the material.
- Using ether PLOS or PCS show districts their Longitudinal Crack Sealing needs.
- HQ Equipment to do scheduling and META to supply training for the LCSM.

Method of Crack Sealing/Filling:

- Determine crew size?
- Need to determine the best recommended Longitudinal Joint sealing method.

APPENDIX B

TTLS Technical Information

Information is in electronic form only on TTLS Final Report DVD
Caltrans Division of Research and Innovation Task Order 02-10
Master Agreement 65A0049   January, 20 2006

- <u>Electrical</u>
  - Electrical Components
  - Trailer Electrical
  - Truck Electrical

- <u>Hydraulics</u>
  - Hydraulic Parts
  - Trailer Hydraulic Diagram
  - Truck Hydraulic Diagram

- <u>Programs</u>
  - Automation Direct Software
  - iDRN-ST
  - Trailer Panel Program
  - Trailer User Program
  - Truck Panel Program
  - Truck User Program
  - Voice Messages

- <u>TTLS Fabrication Drawings</u>
  - 2TLS-100 Series Drawings – Application Bar on Application Truck
  - 2TLS-300 Series Drawings – Transfer Trailer
  - 2TLS-400 Series Drawings – Sealant Transfer Hose on Transfer Trailer
  - 2TLS-500 Series Drawings – Application Truck
  - 2TLS-600 Series Drawings – Common Parts to Truck and Trailer

APPENDIX C

TTLS General Information

Information is in electronic form only on TTLS Final Report DVD
Caltrans Division of Research and Innovation Task Order 02-10
Master Agreement 65A0049 January, 20 2006

- Cost Information
  - Fabrication Costs
  - Purchase Orders
- MSDS Information
  - Crafco Sealant MSDS
  - Heat Transfer Oil MSDS
  - Hydraulic Oil MSDS
  - Propane MSDS
- TTLS Media
  - Hwy4 Video
  - Hwy113 Pictures
  - LCSM2 Two Pager Report
  - LCSM2 Video
  - TTLS Equipment Pictures
  - TTLS Two Pager Report