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Effectiveness Study of UNL's Crack Routing Device (CRD) –Phase II

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16. Abstract This project evaluated the crack routing device (CRD) for effectiveness in improving current crack-cutting practices and for possible adoption as a standard in the Nebraska Department of Roads (NDOR). To enact these evaluations of CRD, the research team collaborated with NDOR to conduct surveys and field tests. Given the positive results obtained from this project, improved road-maintenance practices are anticipated when CRD is used, and this research therefore recommends the adoption of CRD in crack-routing work.		
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List of Abbreviations

CCD: Crack Cleaning Device
CRD: Crack Routing Device
DOT: Department of Transportation
FHWA: Federal Highway Administration
HP: Horse Power
NDOR: Nebraska Department of Roads
TAC: NDOR Technical Advisory Committee
UFC: Unified Facilities Criteria

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Disclaimer

Executive Summary

This project evaluated the crack routing device (CRD) for effectiveness in improving current crack- and joint-routing practices and for possible adoption as a standard for the Nebraska Department of Roads (NDOR). Up to the current stage, CRD has been developed through field testing and evaluation/feedback in order to create a more reliable, effective, and safer crack routing device in the sole hope of contributing to the current road maintenance practices in the U.S. To validate CRD in the field and to gain industry acceptance of the technology, several industry demonstrations and field tests have been conducted during 2016 in the cities of Lincoln and York, NE. Productivity data, along with the crews' feedback, were collected during the field tests. The analyzed results showed that the CRD design concepts have been well received by most of the participants, who expect that CRD would positively impact highway road maintenance by improving safety and productivity while reducing maintenance costs.

The various field tests and evaluations have revealed satisfactory achievements in performance, quality, safety, and control as well as have demonstrated the high potential of workers to utilize CRD in crack-routing practice. We expect the following benefits from the successfully designed and validated CRD:

(1) Decreased safety risk in routing operations

(2) Enhanced maneuverability in following cracks

With the positive results obtained from this project, we recommend the adoption of CRD in crack-cutting work as a supplementary device that aligns with existing equipment.

Chapter 1: Introduction

Cracks in pavement occur when stress builds up and is relieved on the surface layers. Different crack repairing methods are typically used to repair pavement surfaces, depending on crack size and crack type. The Federal Highway Administration (FHWA-RD-99-147) has recommended crack sealing for small cracks ranging from 5 to 19 mm (Smith *et al*. 1999). Furthermore, as demonstrated in Table 1.1, Unified Facilities Criteria (UFC) provides guidelines for crack preparation based on crack size (Basham 2001).

Table 1.1 Crack preparation methods based on crack size (Basham 2001)

Crack Size	Cleaning Methods
Hairline cracks: less than ¼ inch	No preparation required
Small cracks: ¼ to ¾ inch	Routing to widen the cracks to a nominal width of 1/8 inch greater than existing nominal or average width
Medium cracks: ¾ to 2 inches	Sandblast, heat lance, or wire brushes, followed by compressed air
Large cracks: greater than 2 inches	Cut and filled, prepared in the same manner as potholes

The conventional methods for preparing roadway cracks are typically ineffective, labor intensive, and dusty, and work crews may also face safety hazards (*e.g.*, a rollover and/or being crushed by the equipment). Among all methods, routing is the best approach for small crack preparation. However, the heavy routers typically used by most state DOT agencies for routing small cracks have several obvious shortcomings, such as extreme weight, unsafe operation, slow mobility, and high cost.

The creation of a novel crack routing device was initiated through a practical request from NDOR for a tool that efficiently cut cracks and addressed the aforementioned limitations. Based on those needs, a customizable Crack Routing Device (CRD) was developed by the research team. During this research, several demonstrations and field tests were conducted with multiple versions of CRD, and the equipment was upgraded based on the feedback and suggestions collected.

Chapter 2: Background

Safety factors are generally a main concern for construction sites due to the frequency of work-related injuries and accidents (Shapira 2005; Nunnally 2000; Heravi and Rafsanjani 2011; Peurifoy *et al*. 2006). Accordingly, safety is always a top priority in any project lifecycle, from beginning to end. In this context, it is extremely critical to discover all the factors that are significant in order to develop proper safety programs that lead to the highest level of safety in a construction site. The previous study (Cho and Ahn 2014) confirmed that NDOR road maintenance teams also consider safety the most important factor in road maintenance operations. The survey results from NDOR superintendents and crews indicated that they are much more concerned about safety compared to productivity and quality in their crack cleaning and routing operations (Park *et al*. 2015).

To address such concerns, a multi-function Crack Cleaning Device (CCD)—one able to rout cracks and clean stubborn vegetation and accumulated de-icing materials from pavement cracks—was designed and manufactured during the previous study supported by NDOR (Cho and Ahn 2014). Multiple CCD units have been used by NDOR since 2014. However, the evaluation of this device demonstrates that it does not perform properly during crack-routing processes since the CCD is mainly designed for crack cleaning (Cho and Ahn 2014; Park *et al*. 2015). In particular, the following technical challenges were identified in using CCD for routing cracks:

(1) Lack of blade torque in cutting cracks: The initial design of the CCD used a light-weight, 1.25 horsepower (HP) engine in order to reduce safety risks and enhance maneuverability. However, routing cracks, particularly cracks on concrete pavement, requires blade rotation with much more torque and power.

(2) Lack of stability and controllability in using the device for routing cracks: Operator strength is required to engage CCD in routing cracks due to its light weight. In addition, its current design does not allow CCD to create a consistent depth of routing.

To this end, NDOR initiated research to effectively address the drawbacks of the CCD as well as the safety risks arising while using a conventional router (*e.g.*, Crafco router)—the heavy weight and pulling mechanism of the conventional router put its operator at significant risk of a rollover and/or of being crushed by the router. Based on the design of CCD, the new device was designed to utilize a pneumatically powered rotary attachment to cut small-to-mid-sized pavement cracks. The use of a pneumatic motor allows CRD to continue to have a relatively light weight and small size compared to the conventional router. Along with its pushing mechanism, these features will significantly reduce the safety risk in routing cracks. In addition, CRD is designed to address the drawbacks of the CCD as follows:

(1) Increase available power: CRD adopts a 4-hp engine and is expected to provide more torque and faster rotation speed for its blade.

(2) Enhance stability and controllability: The design's four wheels, heavier weight, and shorter body length are expected to provide better stability for CRD's operation. In addition, its new feature, which controls the cutting depth of the blade, is expected to enhance controllability.

Chapter 3: System Concept and Functions

CRD was developed as a tool that could efficiently prepare pavement cracks and joints for sealing. The simple and innovative design of this tool is an air-powered, rotary cutting bit-attachment system that features an air nozzle—inherited from the CCD design—to help simultaneously blow out the pavement crack behind the rotary attachment. The main parts and functions of CRD are shown in Figure 3.1. CRD incorporates a high-torque, pneumatic, rotary motor that connects seamlessly with existing maintenance vehicles' air compressor systems, thereby reducing further retrofitting costs and eliminating the need for flammable liquid fuel.

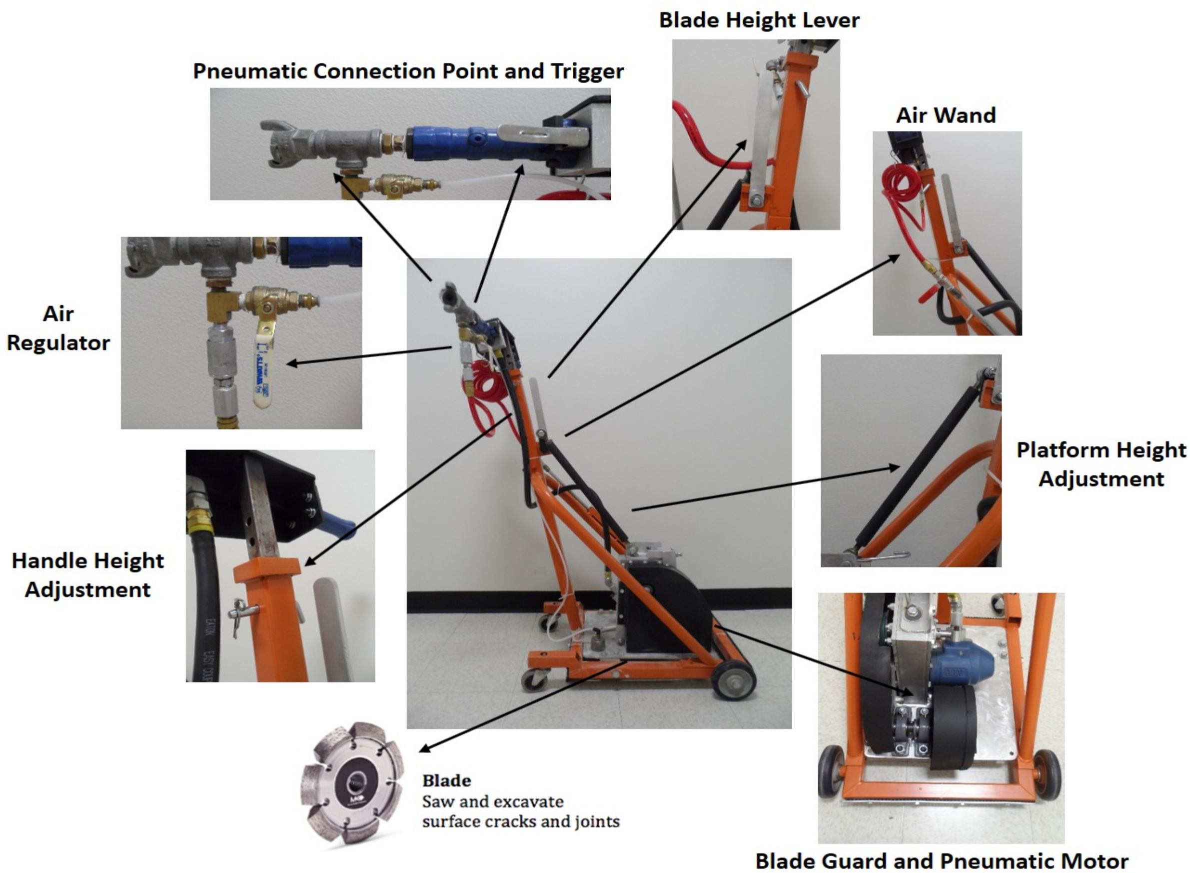

Figure 3.1 Configuration of CRD

The weight of CRD is approximately 100 lbs.; this study found the weight to be sufficient to keep the equipment stabilized while alleviating operator fatigue during its operation. In addition, the weight ensures relatively easy loading and unloading of CRD from a truck or trailer; loading and unloading of the conventional routers, which generally weigh over 500 lbs., require additional effort and may cause safety risks.

Figure 3.2 Difficulties in loading/unloading the existing equipment

CRD uses a cutting saw (*i.e.*, blade) in a pneumatic manner, making it suitable for routing and widening cracks in both concrete and asphalt surfaces. Similar to CCD, an air blasting nozzle directly behind the blade attachment expels fine-grained particulate (*e.g.*, concrete and asphalt dust) from the crack.

Machinery and equipment are usually designed in such a way that various operators with different physical conditions can easily work with a device—if a device is difficult to work with, it will lead to operator fatigue and a higher safety risk. In order to provide convenient conditions for operators with different heights, a height-adjustable handle was designed. This adjustable handle significantly improves the maneuverability of CRD for an operator. Further, a platform-height control to adjust the level of the platform has been included with the design to help CRD work on different surface levels.

Although a rear nozzle behind the rotary attachment produces enough air to clean loose particles from cracks, a larger volume of air is still needed to clean or chase away the dirt, debris, and/or vegetation on the pavement surface that results from the crack-routing process. Conventionally, a separate leaf blower or an air wand directly connected to an air compressor is used to clean the pavement surface after cracks are cut. However, it is considered an additional task on a jobsite and therefore increases the costs as well as the number of operators associated with the crack-routing process. In order to eliminate this additional task, an air wand with a 3/8" inner diameter was connected to CRD in the same manner as the previous CCD. After routing, the air wand can be used to clean cracks and the pavement surface. This mainly helps eliminate the process of disconnecting CRD from the air compressor to use a traditional air wand to clean the pavement.

Chapter 4: Performance Tests

Multiple different versions of the CRD unit have been manufactured and used by the researchers and NDOR crews in order to test its performance as well as to train crews and provide demonstrations.

4.1 Training and Demonstration Sessions

Several outdoor training and demonstration sessions were performed at an NDOR district yard in Lincoln, NE. NDOR was asked to let its crews work with CRD in order to become familiar with its operation. During such sessions, the crews were also asked to share their ideas and give feedback about CRD's performance, which helped improve the CRD design and enabled achievement of the device's highest performance. It was also observed that the crews quickly learned the operation of CRD and started to comfortably route cracks.

Figure 4.1 Training and demonstration sessions at the Lincoln yard

4.2 Field Tests: Lincoln Yard

During 2016, the research team routinely visited the NDOR yard in Lincoln, NE to test and measure the performance of CRD in the field (Figure 4.2). The main purpose of the NDOR field tests was to test how well the device cut cracks and to observe how well different versions performed for crews with different physical conditions. This process was necessary to be sure each version of the device was suitable for all crews and to obtain their comments and feedback.

The tests were conducted under different weather conditions and on different sizes and types of cracks in order to ensure that CRD could perform at a wide variety of project sites. During these tests, the routing function of CRD was tested in conditions similar or equal to those typically encountered while using conventional crack cutting devices on a project site. The innovative design of CRD allowed for more efficient use and safer conditions during tests. It was also determined that the device's 100 lbs. of weight is sufficient to help the device easily cut cracks.

Figure 4.2 Field tests at the Lincoln yard

4.3 Field Test: York Yard

In order to make a proper comparison between the performance of CRD and the existing device used by NDOR, a field test was conducted in October 2016 at NDOR's location in York, NE (Figure 4.3). For this test, 14 crew members worked with both devices (*i.e.*, CRD vs. Crafco router) to cut cracks in asphalt and concrete surfaces. NDOR was asked to select crews with experience working with the department's existing device to participate in the test. Fourteen crews were selected and participated based on NDOR recommendations. Both devices were tested by each crew separately on both asphalt and concrete surfaces and under conditions similar to those encountered while working at real project sites. The tested cracks were generally vertical or transverse.

During each test, quantitative data and user feedback were collected through a survey (Appendix A) designed by the researchers and approved by NDOR. Table 4.1 lists the feedback NDOR's crew provided while comparing CRD with the existing machine. In addition, Figure 4.4 shows the quality of cracks routed by CRD.

Figure 4.3 Field test at the York yard

Table 4.1 Field-observed and -surveyed comparison data for CRD and existing equipment

Criteria	Existing Equipment	CRD
Estimated Equipment Purchase Cost	$10,000 ~ $15,000	$3,000 ~ $4,000
Engine Type	Combustion engine (2 cylinder)	Pneumatic rotary motor
Engine Power (hp)	30 hp	4 hp
Wight	534 lbs.	100 lbs.
Average Productivity (for straight not random cracks)	0.75 miles/hour (asphalt) 0.60 miles/hour (concrete)	0.25 miles/hour (for both asphalt and concrete)
Crew Size	2	1
Pros	More power, ideal for straight-line cracks or joints	Safe, flexible, more maneuverability
Cons	Heavy, expensive, hard to handle on inclines and windy days	Requires a stronger motor
Best Working Conditions	Straight-line cracks or joints, longitudinal cracks	Random cracks, longitudinal cracks, transverse cracks

CRD allowed for a more efficient use of labor by improving the maneuverability and reducing safety risks. In addition, based on the field operators' statements, the existing machine is difficult to pull and control, especially against strong winds created by nature or passing vehicles (Cho and Ahn 2014). On inclines, such strong winds can topple the router onto the operator. Comparatively, CRD requires a pushing motion rather than a pulling motion and does not have a mass large enough to be affected by wind, which allows for ease of control. Therefore, CRD provides a safer working environment. In addition, CRD is much lighter than existing equipment and provides better control as to the desired depth cut for curved, random cracks. Overall, the crew determined that CRD could be considered as a supplement to the existing equipment.

Figure 4.4 Cracks routed by CRD in concrete pavement

Chapter 5: Survey Analysis

Selecting the right machinery and equipment has been shown to be critical to the success of a construction project (Shapira 2005; O'Brien *et al*. 1996; Schaufelberger 1999; Nunnally 2000; Harris and McCaffer 2001; Peurifoy *et al*. 2006). During this selection process, various factors and parameters need to be carefully considered and evaluated. In particular, the experience of machinery/equipment operators plays a critical role. In order to cover a variety of operator experiences, a survey was designed and conducted during the York, NE, field tests. The survey criteria were composed based on the three factors: (1) safety, (2) productivity, and (3) quality (see Appendix A.). In order to better understand the responses, all of the qualitative factors were changed to quantitative numbers (such as 1 to 5), and the crews were asked to make a numerical evaluation. Each crew first worked with the device and then filled out the survey (see Appendix B.). Since the majority of crews have more than ten years of working experience with the existing device (Figure 5.1), their responses to the questions provided a valuable opportunity to make an appropriate comparison between CRD and existing equipment.

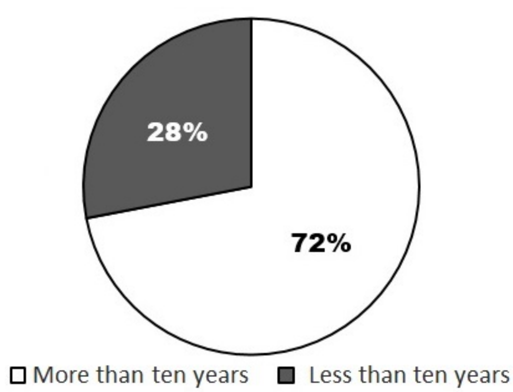

Figure 5.1 Working experience (years) of crews in maintenance work and with existing equipment (Questions 1 and 3 of survey)

While Table 4.1 indicates that the main disadvantages of the existing device are high safety risk and less maneuverability, Figure 5.2 shows that CRD provides a safer environment for operators. Providing a jobsite with the lowest safety risk is always a main challenge for a manager at a site. Therefore, the safety provided by CRD could be a great help on a project site. In addition, since the existing equipment used by NDOR has only two wheels, it needs to be constantly balanced. Such instability creates higher risks for the operator. However, the four wheels of CRD provide constant balance for the equipment and thereby decrease operator risk.

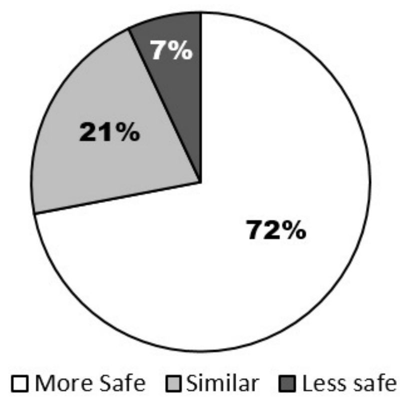

Figure 5.2 Safety degree of CRD compared to the existing equipment (Question 6)

Furthermore, Figure 5.3 shows that the operators found CRD easier to control than the existing device. Such advantages help reduce operator fatigue, which usually increases when the operator cannot easily control machinery and equipment on sloped and uneven surfaces or on random cracks.

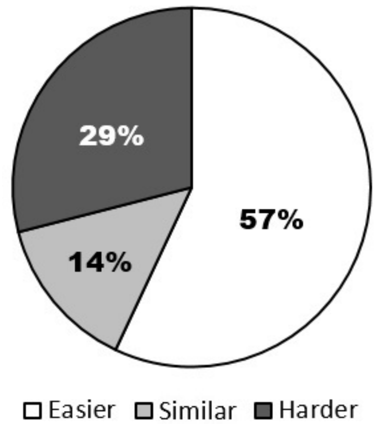

Figure 5.3 Maneuverability of CRD compared to the existing equipment (Question 7)

The main function of both CRD and the current equipment is crack cutting. Therefore, tracking a crack correctly is significant in determining the success of a piece of equipment; more difficulty in tracking cracks means less productivity. Figure 5.4 indicates that compared to existing equipment, CRD can track cracks more easily. The designed platform of CRD, with two rotating back casters, leads to better tracking.

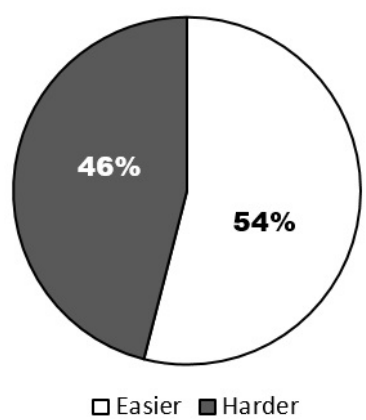

Figure 5.4 Crack tracking of CRD compared to the existing equipment (Question 11)

Overall, by providing more safety and maneuverability for operators as well as easier crack tracking, CRD seems to be an appropriate supplemental machine for the existing equipment. Figure 5.5 also indicates that the majority of workers also confirmed that CRD could be considered as supplemental equipment on NDOR jobsites in which roads are sloped or random cracks exist.

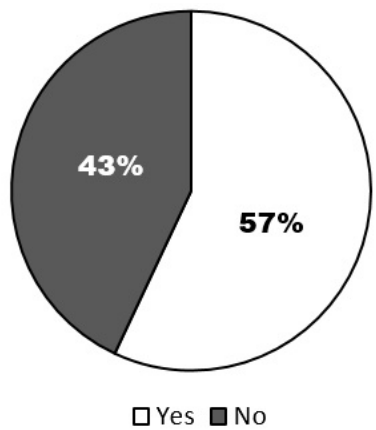

Figure 5.5 Consider CRD as supplemental to the existing equipment (Question 14)

In addition to the aforementioned advantages, CRD is a pneumatic device, which avoids the need for flammable liquid fuel. Flammable materials provide a high level of risk on a jobsite, so providing and carrying such materials also adds extra indirect costs to the total project. However, since CRD is a pneumatic device, it avoids all such risks. Furthermore, Table 4.1 indicates that CRD reduces the crew size, reducing the direct and indirect costs associated with an extra person.

It must be noted that the research team received feedback suggesting the benefit of more power and speed during crack cutting. In the case of productivity, as Table 4.1 shows, CRD's productivity is about a third of the existing equipment, since the existing equipment uses a more powerful combustion engine and heavier weight, which helps push down the unit and cut cracks faster. However, it should be noted that the productivity of existing equipment would be significantly reduced when random cracks exist or operation is required on uphill.

Chapter 6: Conclusions

In this report, crack-routing field tests were conducted at two locations in the state of Nebraska to evaluate the effectiveness of CRD compared with NDOR's existing equipment. Based on the collected evaluations and comments from NDOR at both the Lincoln and York locations, this study found a strong potential for using CRD to improve crack and joint cutting. The tests demonstrated CRD's excellence in performance, and a survey completed by the crews who had experience working with NDOR's existing routers confirmed the system's feasibility.

The major findings of the research team during this project are as follow:

- The team collected positive and promising feedback through several field tests. The feedback shows that CRD is a reasonable supplement to existing equipment. In particular, CRD works well for random, longitudinal, and transverse cracks on both uphill and downhill slopes.
- Most operators reported that CRD offers a safer alternative to the existing methods. In addition, it provides operators with more flexibility and maneuverability.
- Although CRD's current productivity is around a third of existing equipment, its advantages validate using it as supplemental equipment.

In summary, the various field tests and evaluations revealed satisfactory achievements in performance, quality, safety, and control; additionally, these tests identified the high potential of using CRD in crack-cutting practices. To this end, this research recommends CRD as a supplemental device for cutting pavement cracks for jobsites in which roads are sloped or on which random cracks exist. Our future research will focus on developing a routing device with a more powerful motor to increase productivity.

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Appendix A: Survey Questions

1. How many years of work experience do you have in maintenance work?

- < 1
- 1-3
- 3-10
- > 10

2. What is the current method being used to prepare/route cracks?

- Crack Router (Model name: ___________________)
- Others _________________________

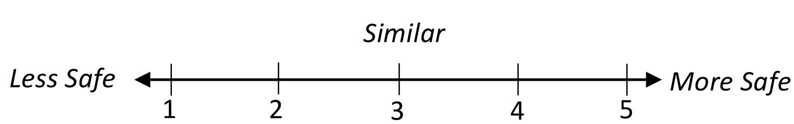
3. How many years of work experience do you have with existing equipment?

- < 1
- 1-3
- 3-10
- > 10
- NA

4. What is the typical crew size for preparing/routing the cracks with the current method?

5. What would be the estimated hourly cost in preparing/routing the cracks with the current method? e.g., hourly labor cost, fuel or maintenance cost.

6. How do you feel about safety degree of CRD compared to the existing equipment? E.g., loading and unloading, operation, etc.



7. How do you feel about maneuverability of CRD compared to the existing equipment?

Harder to Maneuver	1	2	3 (*Similar*)	4	5	*Easier to Maneuver*

8. How do you feel about quality of crack routed by CRD compared to the existing equipment?

Less Consistent	1	2	3 (*Similar*)	4	5	*More Consistent*

9. How do you feel about operation speed of CRD compared to the existing equipment?

Slower	1	2	3 (*Similar*)	4	5	*Faster*

10. Does CRD have enough power to do its necessary work?

- Yes
- No

11. Is CRD easy to follow random cracks?

- Yes
- No
- Other comment: ____

12. Are there any troubles with any part of CRD or the process?

- Yes, please mention ____
- No

13. Would you be considering to use CRD over the existing equipment?

- Yes, please specify the reason ____________________________________

- No, please specify the reason _____________________________________

14. Would you be considering to use CRD (as supplementary equipment) with the existing equipment?

- Yes, please specify its envisioned use _____________________________

- No, please specify the reason _____________________________________

15. What would be the recommended purchase cost of CRD? (The purchase cost of Crafco router is $10,000~$15,000)

- <$2000
- $2000 - $3000
- $3000 - $4000
- $4000 - $5,000
- >$5,000
- Or, any specific amount: __________

16. Any suggestions for improving CRD performance or design?

Appendix B: Summary of Survey Results

Respondent	Questions													
	1	3	4	5	6	7	8	9	10	11	12	13	14	15
# 1	>10	>10	2-3	N/A	3	2	3	1	No	No	Yes	No	No	N/A
# 2	>10	>10	2	N/A	4	3	2	1	No	No	Yes	No	No	3k-4
# 3	>10	>10	8	N/A	3	4	2	2	No	Yes	Yes	No	No	3k-4
# 4	1-3	N/A	4	N/A	2	5	4	3	Yes	Yes	Yes	Yes	Yes	3k-4
# 5	>10	>10	2	N/A	4	3	3	1	No	No	Yes	No	Yes	3k-4
# 6	1-3	1-3	4-5	N/A	5	4	2	1	No	No	Yes	No	Yes	3k-4
# 7	3-10	3-10	4-8	N/A	5	5	2	1	No	No	Yes	No	Yes	3k-4
# 8	>10	>10	8	N/A	4	2	2	1	No	Yes	No	No	No	N/A
# 9	>10	>10	3	$100	4	1	3	1	No	No	Yes	No	No	N/A
# 10	>10	>10	4	N/A	4	4	N/A	N/A	N/A	N/A	N/A	N/A	Yes	<2K
# 11	>10	>10	4-6	N/A	3	2	1	1	No	Yes	Yes	No	No	<2K
# 12	>10	>10	2	N/A	4	4	3	1	No	Yes	Yes	No	Yes	<2K
# 13	>10	>10	4	N/A	4	4	4	2	No	Yes	Yes	Yes	Yes	4k-5
# 14	3-10	3-10	4	$80	5	4	3	2	No	Yes	Yes	Yes	Yes	4k-5