FIRST AMENDATORY AGREEMENT

THIS FIRST AMENDATORY AGREEMENT is entered into as of the date indicated on the signature page, by and between the **CITY AND COUNTY OF DENVER**, a Colorado municipal corporation ("City"), Party of the First Part, and **UNIVERSITY CORPORATION FOR ATMOSPHERIC RESEARCH (UCAR)**, a nonprofit corporation authorized to conduct business in the state of Colorado (the "Consultant"), Party of the Second Part;

WITNESSETH

WHEREAS, the parties entered into an Agreement dated June 28, 2015 ("Existing Agreement") in which the Consultant agreed to provide consulting services for weather forecasting and pavement treatment recommendations for runways, taxiways, ramp areas and roadways at **DEN**; and

WHEREAS, the parties desire to amend the Existing Agreement by increasing the length of the term of the agreement and maximum contract amount; and

NOW, THEREFORE, for and in consideration of the premises and other good and valuable consideration, the parties hereto agree as follows:

1. **Section 5 TERM** is hereby amended by deleting Section 5 in its entirety and replacing it with the following:

   "**5. TERM:** The Term of this Agreement shall commence on January 1, 2016 and shall terminate on December 31, 2021, unless sooner terminated."

2. **Section 4. A. MAXIMUM CONTRACT LIABILITY; FUNDING** is hereby amended by deleting Section 4. A. and replacing it with the following:

   "A. Any other provision of this Agreement notwithstanding, in no event shall the City be liable for payment for services rendered and expenses incurred by the Consultant under the terms of this Agreement for any amount in excess of the sum of Six Hundred One Thousand Seven Hundred-Thirty Dollars and Zero Cents ($601,730.00). The Maximum Contract Liability may only be increased by amendment to this Agreement."

3. **Exhibit C Scope of Work** is hereby added to this Agreement.

This First Amendatory Agreement shall not be effective or binding on the City until fully executed by all signatories of the City and County of Denver.

[END OF PAGE]

Contract Control Number: PLANE-201522205-01

Contractor Name: UNIVERSITY CORPORATION FOR ATMOSPHRC RES

By: Amy M. Smith

Name: Amy M. Smith
(please print)

Title: Manager, UCAR Contracts
(please print)

ATTEST: [if required]

By: _____

Name: _____
(please print)

Title: _____
(please print)

Contract Control Number:

IN WITNESS WHEREOF, the parties have set their hands and affixed their seals at Denver, Colorado as of

SEAL

CITY AND COUNTY OF DENVER

ATTEST:

By_____

_____

APPROVED AS TO FORM:

REGISTERED AND COUNTERSIGNED:

By_____

By_____

By_____

NCAR

NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

OFFICE OF THE DIRECTOR

February 28, 2018

Mr. Mike Carlson C.M, ACE
Assistance Director of Operations – Airside
Denver International Airport
Airport Operations/Airport Office Building
10th Floor/8500 Peña Boulevard
Denver, CO 80249-6340

Dear Mr. Carlson:

I am pleased to submit for your consideration NCAR proposal #2018-0261 entitled, "Denver International Airport MDSS Demonstration, Research and Development." Dr. Seth Linden is NCAR's Principal Investigator on this project. The total Cost Reimbursable amount requested for NCAR is $356,730. Please note that UCAR/NCAR participation in this project is contingent upon mutually agreed upon terms and conditions.

Should Denver International Airport choose to award the proposal, funds for NCAR (DUNS# 078339587) should be provided by direct agreement with the University Corporation for Atmospheric Research. Arrangements can be made with:

Ms. Amy Smith
Manager, UCAR Contracts
University Corporation for Atmospheric Research
3090 Center Green Drive
Boulder, CO 80301-2252
Telephone (303) 497-8872
Email: fedaward@ucar.edu

Please refer to the NCAR proposal number on all correspondence with UCAR.

Should you have questions regarding the proposal, please contact Dr. Linden at (303) 497-8433 or, on administrative matters, contact the NCAR Budget and Planning Office, Ms. Valerie Koch at (303) 497-1113.

Sincerely,

Valerie N. Koch

Valerie N. Koch
Manager, NCAR Budget and Planning

Enclosure

cc: UCAR Contracts Office
NCAR B&P
J. Zoetewey, RAL

EXHIBIT C

Denver International Airport MDSS Demonstration, Research and Development

STATEMENT OF WORK FOR THE PROVISION OF MAINTENANCE DECISION SUPPORT SYSTEM (MDSS) RESEARCH AND DEVELOPMENT TO THE CITY AND COUNTY OF DENVER/DENVER INTERNATIONAL AIRPORT (DEN)

Prepared by the
University Corporation for Atmospheric Research

Date: 09 February 2018

I. Background

In an effort to mitigate the challenges associated with winter maintenance decisions, the Federal Highway Administration (FHWA) initiated a program in 2001 aimed at developing a winter road Maintenance Decision Support System (MDSS). The primary goal of the MDSS program was to construct a functional prototype MDSS that could provide objective guidance to winter road maintenance decision-makers concerning the appropriate treatment strategies to employ to control roadway snow and ice during adverse winter weather events.

The FHWA MDSS prototype utilizes current weather observations and numerical model predictions from multiple sources to produce route-specific or runway-specific analyses and forecasts of environmental conditions. Output from this process is used to drive an energy balance model to generate predictions of pavement conditions along each route of interest. Together, environmental and road condition information is used to construct recommended treatments, which are based on standard rules of practice for effective deicing and anti-icing operations. An interactive Java-based display is used to visualize graphic and text-based treatment recommendations, as well as diagnostic and prognostic atmosphere and road condition data.

The broad needs met by the current MDSS include the following:

- Centralized Weather Support
- Enhanced Strategic Planning Capability
- Improved Tactical Response Capability
- Improved Adverse Road Weather Notification
- Operation-Specific Decision Support

The National Center for Atmospheric Research (NCAR), which is operated by the University Corporation for Atmospheric Research (UCAR), created a custom version of the FHWA MDSS for Colorado with a specific focus on Denver International Airport (DEN) runway operations. Over the winters of 2012-2015 and 2016-2019, UCAR and the City and County of Denver, which operates DEN, entered into an agreement for the provision of MDSS services and support to DEN. This project will be enhancing the MDSS DEN system with better display technology, new custom models and also some new work related to runway friction and condition prediction. This document describes a continuation of the DEN MDSS efforts for the next three years (2019 – 2021).

II. Deliverables and Services Term: 1/1/2019-12/31/2021

UCAR shall provide deliverables consistent with the following MDSS technical documents.

Table 1. MDSS Project Related Documents

Document and/or Web Sites	Source
Maintenance Decision Support System (MDSS) Project, FHWA. http://www.rap.ucar.edu/projects/rdwx_mdss/xdss/xdss.jnlp	National Center for Atmospheric Research
Maintenance Decision Support System (MDSS) Release-6.6 Draft Technical Description, Dated 10 March 2015. Available upon request.	National Center for Atmospheric Research

a. MDSS Elements and Parameters

The MDSS system shall provide a set of guidance products for airport operation maintenance managers and crews that provides a forecast of weather and pavement conditions and treatment recommendations customized for specific runways, taxiways, and ramp areas, as well as roadways of interest. UCAR will ensure that MDSS is delivering the same forecast products as it has been over the last six years. Refer to the previous SOW for a detailed list of forecast variables and products.

b. UCAR shall provide to Denver International Airport an MDSS system tailored for the airport's operations.

The MDSS shall have core components including, but not limited to, a fuzzy logic-based weather forecast system, a pavement condition and treatment module, and a data server, which will be operated centrally at UCAR in Boulder, Colorado. The weather forecast system will use advanced data fusion technology developed at UCAR called the Dynamic Integrated foreCast system (DICast™®). The MDSS web server at UCAR will communicate (via the Internet) with local PCs running the display application at DEN facilities. Weather data from DEN's sensors (atmospheric and surface condition data within the airport environment), as well as other key data, will be provided to UCAR via the Meteorological Assimilation Data Ingest System (MADIS) program or acquired directly from DEN via common data transmission methods (e.g., ftp).

MDSS Update Rate:

72-hr weather and pavement condition predictions will be available every hour.

MDSS Temporal Resolution:

Weather and road pavement data will be provided at 1-hr resolution out to 72 hrs.

c. MDSS Operations

Field Demonstration Period:

UCAR, Weathernet (a subcontractor to this work) and DEN staff shall interact as necessary throughout the demonstration period to discuss MDSS operations, configuration, and enhancement plans throughout each of the next three years. These activities may include face-to-face meetings, conducting telecons, or communicating via email.

Best effort will be made to ensure that the MDSS operates 24-hours per day, 7-days per week during this period. UCAR personnel will be available on an on-call basis between 0900 and 1700 MST, Monday through Friday if a critical failure occurs.

UCAR will provide DEN with point of contact information (e.g., cell phone numbers) prior to the start of MDSS operations.

UCAR staff will also be available to respond to comments and questions about the MDSS during normal working hours.

Weather Forecast Advisories

Weathernet staff will provide text-based summaries via e-mail of the predicted weather and road conditions to designated DEN staff members. Weathernet staff will also be available to clarify the weather situation and can be reached using the point of contact information provided by UCAR. Throughout the winter seasons, Weathernet will provide a text forecast four times per day and will be available 24 hours per day for additional support. Weathernet may also provide incident meteorological support on-site during very high-impact situations. During the non-winter months, Weathernet will provide twice per day forecast updates but will still be available 24 hours per day to provide support over the phone or via email.

DEN Winter Maintenance Runways/Routes

The MDSS will be configured to provide weather and pavement condition forecasts and treatment recommendations (i.e., data regarding the atmosphere, surface, and subsurface are available in real-time) for each DEN instrumented runway and/or roadway of interest. DEN representatives, working with UCAR personnel, will select the runways and routes to be used in the MDSS. The runways and routes within DEN's area of responsibility will be characterized using general characteristics (pavement type, subsurface characteristics, etc.). Separate winter maintenance treatment plans will be generated by the MDSS for each of the chosen runways and routes.

d. Verification Report

At the end of each winter season, an end-of-year summary and verification report will be written that will highlight the accuracy of the various forecast elements in the MDSS. The verification report will focus on case studies and verifying how changes / improvements to the system impacts forecast performance. Different elements of the system will be emphasized each year depending on system modifications.

e. MDSS Research and Enhancements

Specific Enhancements in Year 1: New MDSS Display Technology

UCAR will create new MDSS display technology that is compatible with desktop computers and mobile devices. In the last part of the previous contract (2018), UCAR will be working on creating a new mobile-device compatible display. The new display will rely on updated, industry standard GUI software that works well with both desktops and mobile devices. The display will be a web-based (browser-based) application supporting mobile devices and desktop computers. The display will rely on a new backend database that will organize and store all of the data necessary for the display. UCAR will select the database software for the MDSS display backend. Within this first year of the contract UCAR will finish work on the mobile display and make any changes that are necessary. Then UCAR will work on creating a new version of the MDSS display for larger screens such as those available on desktops and laptops. This new desktop/laptop display will be available at the end of the first year of the new contract. The original, Java-based MDSS display will be kept up and running and available through the entire development of the new display.

At a minimum, the new desktop/laptop display will include the following features from the old display (note a number of these features will be scaled down or will not be available in the mobile display):

- Map view (desktop only)
- Dashboard view showing overall alerts for different lead-time-periods
    - Separate alert bars for weather, pavement and blowing-snow
- Event Summary Graph View
- Weather Forecast Graph View
- Road Condition Forecast Graph view
- Ability to show observations on map
    - Selectable RWIS that show current observations
- Ability to show alerts per lead-time-period for given road-segment
    - Selectable road segments that show alerts
- Data archive or playback capability
    - can look at old cases (display is reset to actual past date)

Specific Enhancements in Year 2: Customize NCAR WRF model for Colorado

UCAR will setup a custom WRF model (Weather Research and Forecasting model) over Colorado for MDSS. The WRF model will be integrated with the other NWP models that make up the backend weather forecast engine (DICast) for MDSS and this will enhance the MDSS final forecast. It may also be used independently to help predict banded precipitation events or other hard to predict weather features over Colorado.

The WRF model technology originated at UCAR/NCAR in 2000 and serves as the core NWP (numeric weather prediction) model for many high-resolution modeling efforts around the United States. NCAR has the ability to setup custom WRF model data runs for specific regions and has prior experience doing this for winter-weather in Colorado.

NCAR will setup the latest version of WRF (3.7 or higher). The WRF will be configured to cover Colorado with a 4km spatial domain resolution. This may require a larger grid over the western U.S. at 12km resolution that serves as the boundary conditions for the 4km Colorado domain. NCAR will use a WRF configuration that is more specific to predicting winter-weather and snowfall in Colorado. The WRF model will run 4 times per day, initialized every 6 hours and will produce 1-hourly output out to 36 hours into the future. All standard weather forecast variables will be produced including but not limited to:

- Air temperature
- Dewpoint temperature
- Wind speed and Wind Direction at the surface
- Cloud cover
- Solar Radiation
- Precipitation: liquid rate, snowfall rate, total liquid accumulation, total snow accumulation
- Virtual radar (dBZ forecast)

Specific Enhancements in Year 3: Runway Friction Prediction or Runway Condition (RCAM) Prediction

UCAR will develop algorithms to predict either Runway Friction values (Mu values between 0-1) or predict the Runway Condition Assessment Matrix values: integers from 0-6 that represent how slick the runway is for planes landing.

The friction prediction work for DEN will rely on research performed on a project UCAR currently has with Minneapolis St. Paul International Airport (MSP) to create a Runway Friction Closure Prediction System (RFCPS). The RFCPS system relies on modified MDSS output that incorporates machine learning models to predict runway friction and

the onset and duration of runway closures for Minneapolis–Saint Paul International Airport.

DEN does take some friction measurements but the actual Mu values may be hard to obtain in near real-time or for historic cases. DEN takes other runway measurements that are combined with the friction values to come up with an industry standard RCAM value (Runway Condition Assessment Matrix), which is then used to determine if a specific runway needs to be closed or remain open during winter weather events. DEN has a history of RCAM values that could be combined with other weather data observations in a machine learning context for predicting future RCAM values. UCAR will predict RCAM values between 0-6 and then relate these values to runway closure rules of practice.

The Runway Condition Assessment System (RCAS) work consists of the following steps:

Task 1: Data Acquisition

- Acquire and analyze an archive of RCAM or runway friction data values and associated meteorological observation data from KDEN.

Task 2: Data Quality Control

- After appropriate friction data and observation data have been acquired by NCAR, quality control (QC) algorithms will be applied to the data to remove bad / erroneous data.

Task 3: Data Mining Data Store

- Software will be developed to assemble predictor and target data forming a data store suitable for the application of different machine learning techniques. The software will be capable of outputting data in CSV format.

Task 4: Data Mining / Machine Learning

- Different machine learning techniques will be applied to the RCAM / friction values and meteorological data.
- Machine learning models that relate the weather observations to friction values will be created.

Task 5: Real-Time Algorithm

- A real-time RCAM or Runway Friction prediction application will be created. This will involve the following steps:

- Ingest data sets: RCAM values, friction observations, surface-station observations, radar data, near-term forecast data
- Apply machine learning model(s) to relevant data
- Apply algorithm that relates predicted RCAM values to runway closure start and stop times for each runway
- Run real-time RCAS on NCAR MDSS server
- Provide RCAS prediction output to the new MDSS displays

III. Budget **Term: 1/1/2019-12/31/2021**

The total budget for this three-year project is $356,730, with $118,910 for year one, $118,910 for year two and $118,910 for year three.

UCAR

UCAR Proposal Budget Detail

Proposal #	2018-0261
Proposal Title:	Denver International Airport MDSS Demonstration, Research and Development
UCAR Entity:	NCAR
Period of Performance:	01-01-2019 - 12-31-2021
Principal Investigator	SETH LINDEN

			Unit / Rate	Effort Year 1	Effort Year 2	Effort Year 3	Year 1 City and County of Denver	Year 2 City and County of Denver	Year 3 City and County of Denver	Cumulative Grand Total
Salaries	Regular Salaries	PROJ SCIENTIST II	Hours	0.00	389.84	0.00	0	20,540	0	20,540
		SOFT ENG/PROG I (TBD)	Hours	100.00	0.00	0.00	3,390	0	0	3,390
		SOFT ENG/PROG II	Hours	0.00	0.00	174.04	0	0	7,712	7,712
		SOFT ENG/PROG II	Hours	0.00	0.00	120.00	0	0	4,916	4,916
		SOFT ENG/PROG III	Hours	0.00	40.00	180.00	0	2,227	10,422	12,649
		SOFT ENG/PROG III	Hours	100.00	100.00	150.00	5,517	5,738	8,952	20,207
		SOFT ENG/PROG IV	Hours	20.00	10.00	10.00	1,582	823	856	3,261
		SOFT ENG/PROG IV	Hours	340.07	0.00	0.00	23,638	0	0	23,638
	Subtotal Salaries						34,127	29,328	32,858	96,313
Fringe Benefits		Regular Benefits @	54.90 %				18,736	16,101	18,040	52,877
	Subtotal Fringe Benefits						18,736	16,101	18,040	52,877
	Total Salaries and Benefits						52,863	45,429	50,898	149,190
Purchased Services		Subaward - Weathernet					18,100	18,910	19,720	56,730
	Subtotal Purchased Services						18,100	18,910	19,720	56,730
	Modified Total Direct Costs (MTDC)						70,963	64,339	70,618	206,920
Indirect Costs		NCAR Indirect Cost Rate (MTDC)	56.90 %				40,376	36,609	40,182	117,169
	Total Indirect Costs						40,376	36,609	40,182	117,169
MTDC Costs that Include Indirect Costs	Computing Service Center	Computing Service Center	$7.33 / hr				4,106	3,957	4,647	12,710
	Subtotal MTDC Costs that Include Indirect Costs						4,106	3,957	4,647	12,710
	Total MTDC + Applied Indirect Costs						115,447	104,905	115,447	336,799
Management Fee		UCAR Management Fee	3.00 %				3,463	3,147	3,463	10,073
Exclusions from MTDC	Equipment	Other Equipment					0	10,858	0	10,858
	Balance of Purchased Services >$25K/fiscal year	Subaward - Weathernet					0	0	0	0
	Subtotal Exclusions from MTDC						0	10,858	0	10,858
	Total Funding To UCAR						118,910	118,910	118,910	356,730