Copper in Transit Study

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2.0 Executive Summary

Does it work?

Antimicrobial copper was found to be an effective option for improving the hygiene of touch surfaces in transit. This was demonstrated through on-vehicle testing, as well as in-lab results that showed a 97.5% reduction in the coronavirus surrogate and up to 99.9% reduction in bacteria within 2 hours.

Will it last?

Apart from vandalism of the copper decal product from passengers picking at the exposed edges, the tested products were found to be durable and resilient after 12 months of use. The products showed no significant reduction in thickness and had no indications of dealloying after extended use in transit.

What did people think about it?

The public survey revealed that hygiene on transit surfaces is extremely important in both Vancouver and Toronto; however, it also indicated there may be a knowledge gap for riders in how copper could improve sanitization of surfaces. There would need to be efforts in public engagement to improve awareness of the benefits of antimicrobial copper if it was installed.

3.0 Introduction

Self-disinfecting antimicrobial products on the market expanded rapidly throughout the COVID-19 pandemic, while public pressure to act quickly made it difficult for transit groups to properly investigate products. One solution that showed promise in other industries, but had not been properly validated in transit, was antimicrobial copper (Cu).

TransLink, in Vancouver, began testing antimicrobial materials on their vehicles in 2020 in a three-month pilot study. This study (that was funded by Teck Resources Limited) was completed in collaboration with the Coalition for Community & Healthcare Acquired Infection Reduction (CHAIR), Vancouver Coastal Health (VCH), and the University of British Columbia (UBC) Materials Engineering Department as an extension of previous testing of Cu surfaces in hospitals.

This local pilot study found that Cu killed 99.9% of bacteria in the transit setting[1], and identified several key considerations for implementing Cu in this environment. These findings were shared with the public and contributed to the APTA guidelines for disinfecting transit vehicles during a pandemic (APTA-SS-ISS-WP-001-20).

The pilot was followed by a phase two study that was launched in September 2021 and ended in December 2022. The goal of the second phase was to answer some of the remaining questions from the short pilot, such as the long-term durability, as well as the effectiveness for both bacteria and viruses after prolonged use. Phase two recruited TTC and Mount Sinai Hospital in Toronto to allow a comparison of Cu in two unique climates as well as permitting assessment of additional transit vehicle types (subway and streetcars).

[1] (TransLink, 2021)

4.0 Purpose

The pilot study, along with previous trials of Cu in public spaces[2], demonstrated that antimicrobial Cu had the potential to greatly improve the hygiene of high-touch surfaces; however, there were many questions remaining about the long-term use of Cu in the abusive conditions of public transit.

The objective of this study was to obtain a more comprehensive understanding of antimicrobial Cu in the transit setting and answer three key questions:

- **Does it work (antimicrobial efficacy)?**
- **Will it last (durability)?**
- **What do people think about it (ridership response)?**

5.0 Products

Health Canada mandated the use of only registered products in the study. This meant that even if an unregistered product's Cu content met the classifications specified in Health Canada's Registration Decision (RD2014-15)[3], it could not be considered for the study. This limited the potential products to three options: CuVerro®, CopTek®, and Trimco®.

Table 1: Copper product summary

Product/Vendor	CuVerro®	CopTek®	Trimco®
Application	Coating	Decal/Patch	Solid Cover
Relative Cost	$$	$	$$$
Copper Content	70.6%	89.1%	79.5%
Appearance	Light grey	Bronze coloring	Silver
Surface Finish	Granular texture	Smooth	Brushed metal

[2] (Casey, A.L. 2010. J. Hosp. Infect.), (Mikolay A. 2010. Appl. Microbiol. Biotechnol), (Salgado, C.D. 2015. Infection Control and Hospital Epidemiology), (4. Zerbib 2. 2020. J. Am Med. Dir Assoc)
[3] (Pest Management Regulatory Agency, 2014)

5.1 Copper Coating (CuVerro®)

CuVerro® here on referred to as Cu coating, is a thermal fabrication process that can be applied directly to stanchions or any other hard surface, including plastics. The coating is a copper alloy with a microscopic roughness that gives it a matte grey appearance (Figure 1).

Some of the materials for the engineering assessments required destructive testing at six- and 12-month intervals, because of this, plastic covers were made by Archer Plastics Inc. and sent for coating rather than coating the stanchions directly. These covers were then riveted onto the stanchions and could be removed at the selected intervals thus avoiding any damage to the bus stanchions.

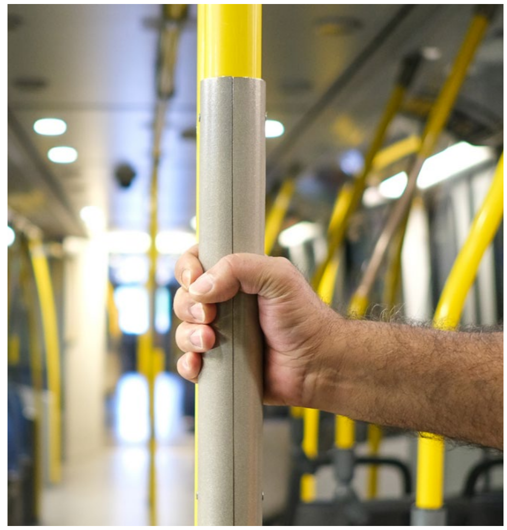

Figure 1: Copper coated stanchion

5.2 Copper Decal (CopTek®)

CopTek®, here on referred to as Cu decal, is an alloy adhesive patch that can be applied directly onto bus stanchions or other flat surfaces. This product has some slight differences from other available Cu decals that were initially considered, such as: Lower Cu content to reduce tarnishing, increased thickness for better durability, and higher glue strength to reduce vandalism.

The effect on antimicrobial performance due to the decreased Cu content, as well as durability improvements were of particular interest in the study.

Figure 2: Copper decal

5.3 Copper Cover (Trimco®)

Trimco®, here on referred to as a Cu cover, was a custom-made copper alloy cover for stanchions. This product was expected to have the best durability as it was a solid metal cover; however, this was also the most expensive option. The potential for increased durability at a higher cost was of significant interest in evaluating this product.

Figure 3: Copper stanchion cover

6.0 Study Design

6.1 Sample Size and Test Point Selection

Vehicle types and sample points were selected early in the planning phase based on lessons learned in the three-month pilot study. Two key decisions were made to minimize potential study bias: a) the use of paired controls for Cu products and b) rotating the location of product types between test vehicles to reduce confounding due to varying levels of use that could occur for individual stanchions. Examples of two vehicle layouts are shown in Figure 4 to illustrate the paired controls and rotated product locations.

Standardized sampling points per vehicle were maximized, while avoiding locations that would have limited use in an effort to reduce this potential confounder. The number of vehicles was then selected to provide a full rotation of the three products between the different configurations.

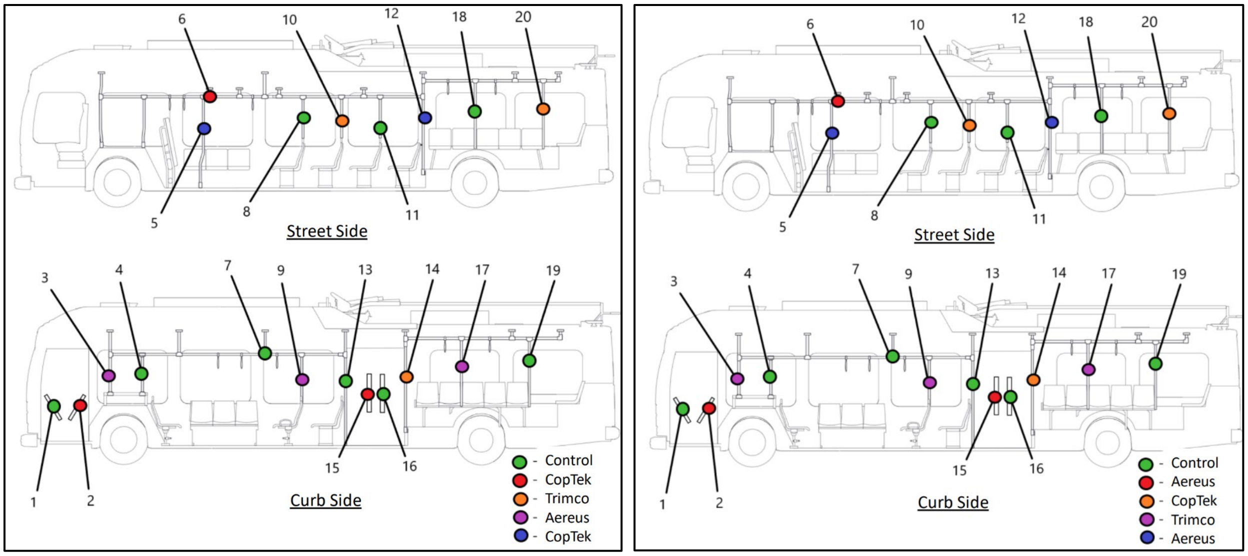

Figure 4: CMBC bus 2108 (left) and 2124 (right) sample points

To confirm that the number of points and sample frequency would be sufficient, a power calculation[4] was completed by VCH to determine the probability of showing a statistical significance in the microbial results. The power calculation was completed using the reference data obtained in the three-month pilot study.

6.2 Test Plan

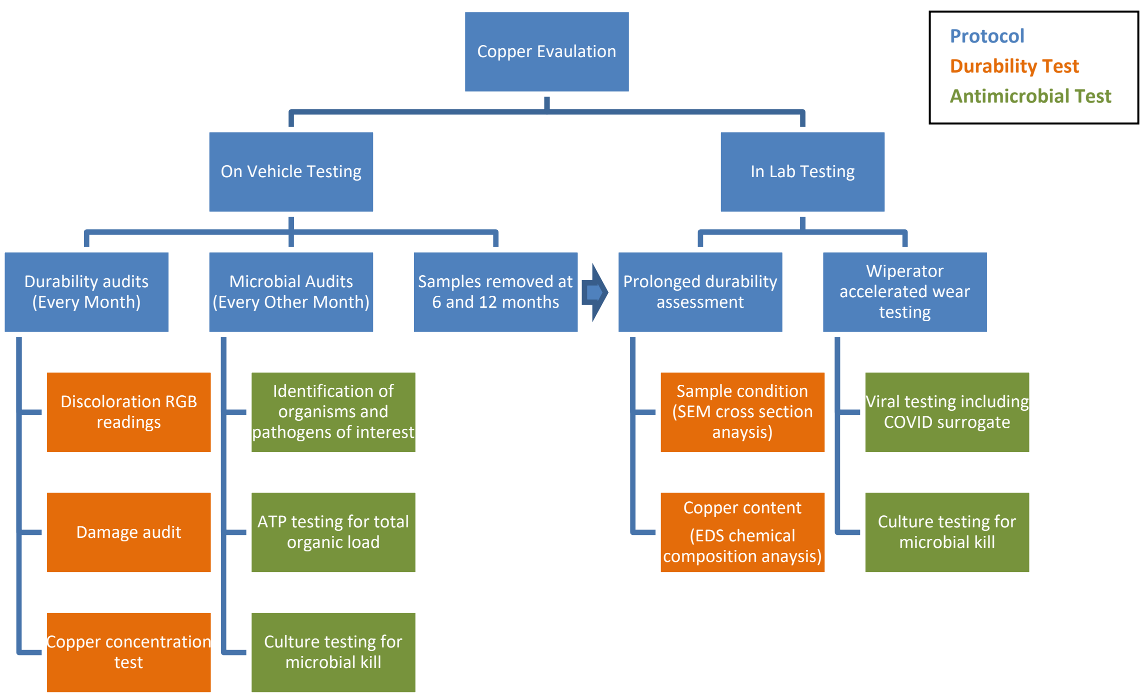

Figure 5: Copper project test plan

[4] (Charles & Lavergne, 2021)

The summary of the test plan is shown in Figure 5. The study consisted of both on vehicle testing, to evaluate the real-world application, and in-lab testing to verify results in a controlled setting. Tests and assessments had two categories: Durability and Antimicrobial Activity.

Vehicles were assessed for monthly durability audits, while antimicrobial audits were conducted every second month. Audits were conducted by Westech® (Vancouver, British Columbia), a third-party group with expertise in cleaning audits for hospitals and other public spaces. Audits were conducted one to three hours after the peak morning traffic. This timing minimized the chances of having very low bacterial counts on both product and control surfaces due to microorganism desiccation.

Detailed durability assessments at six and 12 months necessitated removal of preselected surfaces for transport to the UBC Materials Engineering laboratory. Importantly these surfaces were independent of those used for the monthly evaluations.

Triplicate bacterial testing of vehicular surfaces was conducted and sent to the Vancouver General Hospital and Mount Sinai Medical Microbiology laboratories immediately after sampling. A single sample for Adenosine Triphosphate (ATP) measurement was also performed on all study surfaces. ATP is an organic compound that is pivotal for many energy expending processes in living cells, or cells that were recently living. Therefore, it can be a useful measurement of cell viability or organic matter that is present.

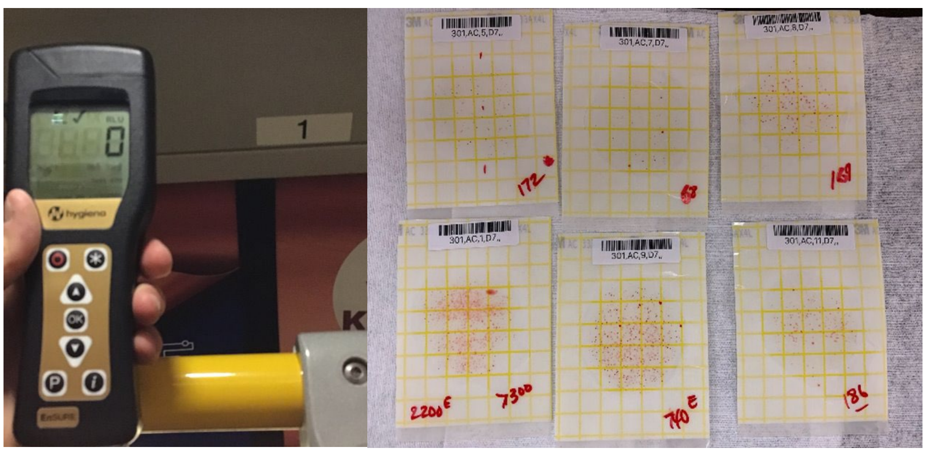

Figure 6: On vehicle testing

While the in-field use data showed antimicrobial efficacy for the Cu products installed in public transit, the collection methods made it difficult to assess their efficacy against viruses after prolonged use and cleaning. It was also difficult to ascertain the effects of the various cleaning agents as well as sweat on the action of Cu. Lab testing was conducted to answer these questions.

Repeated and prolonged cleaning and disinfection was simulated using a Wiperator™ (Filtaflex, Ontario, Canada), a device approved for this purpose by the American Society for Testing Materials. Circular coupons (25 mm diameter) were cut from the provided Cu products as well as the controls, yellow painted steel stanchions, and were placed in the device to then undergo 200 sequential rounds of cleaning and disinfection with either an accelerated hydrogen peroxide (AHP) (Charlotte Products Ltd, ON, Canada), quaternary ammonium disinfectant (Quat) (Buckeye International Inc, MO, USA), or left unwiped as shown in Figure 7. Additionally, selected coupons were wiped with artificial sweat (Biochemazone, AB, Canada) to emulate daily use in the absence of cleaners.

Coupons were then evaluated for antibacterial activity (in triplicate) following the modified Environmental Protection Agency (EPA) protocol using two EPA approved bacteria, *Pseudomonas aeruginosa* or *Staphylococcus* *aureus*. *P. aeruginosa* and *S. aureus* are both opportunistic pathogens that have been linked to serious illness particularly in vulnerable individuals. Antiviral activity was assessed using the EPA approved surrogate strain for SARS-CoV2 as well as a surrogate for human norovirus (a very common cause of gastroenteritis) using the median Tissue Culture infectious dose 50 ($TCID_{50}$) assay. Noroviruses are well known to be difficult to kill as they are resistant to many disinfectants. They also have an ability to survive on surfaces for multiple days which makes them an excellent challenge when assessing the antiviral activity of Cu.

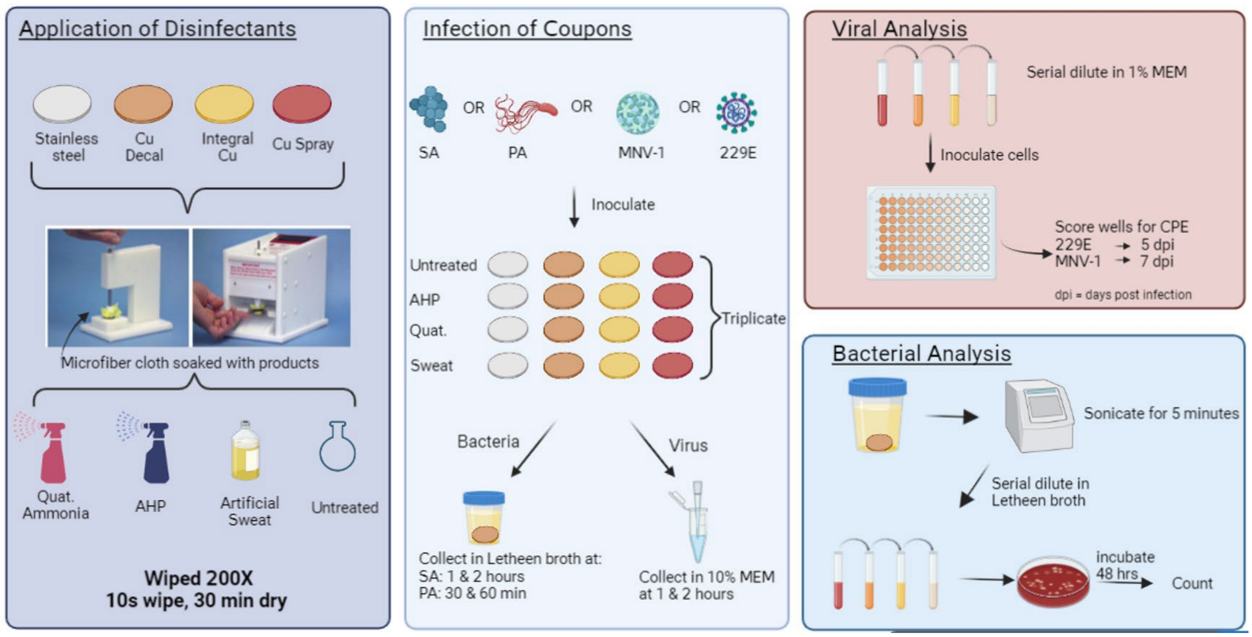

Figure 7: Lab testing protocol

6.3 Public Survey

As part of the study, both TransLink and TTC included antimicrobial Cu questions in their regular rider survey programs for the months of June and July in 2022[5]. The goal of the survey was to gauge the public's opinion on antimicrobial Cu in transit, and the ridership impact it could have if implemented.

Four questions were asked during the survey:

1. Prior to this survey, were you aware of TransLink's Copper Pilot Project to test the ability of copper-based products to destroy bacteria and viruses on high-touch surfaces?
2. I would feel safer riding transit if antimicrobial copper was installed on poles on vehicles (rated from Strongly Agree to Strongly Disagree)
3. Antimicrobial copper on the poles on vehicles would encourage me to take transit more often (rated from Strongly Agree to Strongly Disagree)
4. How important is the hygiene on transit surfaces to your overall satisfaction (rated from 1-10)

[5] (Ryan, Brown, Gaspar, & Chu, 2022)

7.0 Findings

7.1 Antimicrobial Assessment (Does it Work?)

7.1.1 Bacterial Count Results:

After 12 months of in-field use, the combination of all three Cu products exhibited a 42.7% reduction in the CFU compared to the control stanchions (Figure 8). [Toronto showed slightly better bactericidal effects of Cu compared to Vancouver.] Interestingly all transit vehicles in both locations had much lower bacterial numbers on the controls than what has been previously reported in the literature. The reasons for the lower control bacterial counts were likely multiple: a) reduced ridership during the pandemic; b) decreased bacteria on high-touch surfaces because of the use of both gloves and masks (reducing bacterial deposition on surfaces) and c) a general avoidance of touching potentially contaminated surfaces. The reduced bacterial count on the control samplings likely served to underestimate the antimicrobial effects of Cu.

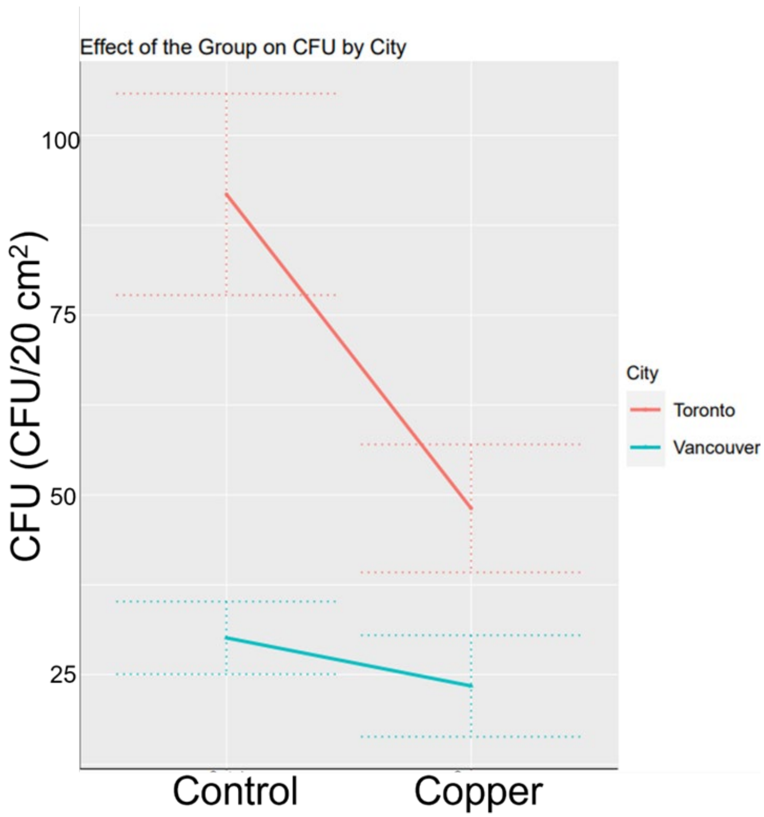

Figure 8: The effect of Cu compared to the control stanchions on the CFU counts after 12 months of in-vehicle use

When each city was separated by their respective vehicle types as displayed in **Table 2,** the greatest CFU reductions were observed on subway cars in Toronto and SkyTrains in Vancouver with a bacterial reduction of 87.5% and 58.6%, respectively.

Table 2: Descriptive table of mean and median of the average CFU by city, vehicle type, and group after 12-months in-field use.

			Control		Copper	
City	Vehicle type	Stanchions (#)	mean[1] (SD)	median[1] (range)	mean[1] (SD)	median[1] (range)
Toronto	Bus	27	40.3 (2)	39.1 (9.2,152.4)	31.6 (2.2)	26.6 (9.2, 214.8)
Toronto	Streetcar	10	45 (1.6)	47.9 (21.8, 95.1)	47.6 (1.5)	45 (22.3, 111.4)
Toronto	Subway	12	175 (1.4)	173.8 (105, 279.9)	21.8 (2.3)	23.7 (6.2, 87.7)
Vancouver	Bus	26	12.4 (2.5)	11.9 (2, 111.9)	12.7 (3.5)	12.6 (1, 133)
Vancouver	Skytrain	35	18.6 (2.8)	18.6 (1.6, 130.3)	7.7 (2.5)	8.7 (1, 38.2)

1: Values listed as colony forming units (CFU); countable bacteria per 20 cm^2 sample area. SD: Standard deviation

7.1.2 ATP results:

All Cu products in both locations demonstrated an average 87.1% reduction in the mean ATP levels, read as relative light units (RLU). In contrast to what was observed with CFU counts, Vancouver displayed higher average RLU values, and a greater percent reduction compared to Toronto, shown in Figure 9. The reason for this is unclear but may reflect the difference in humidity and temperature that occurs seasonally in both locations.

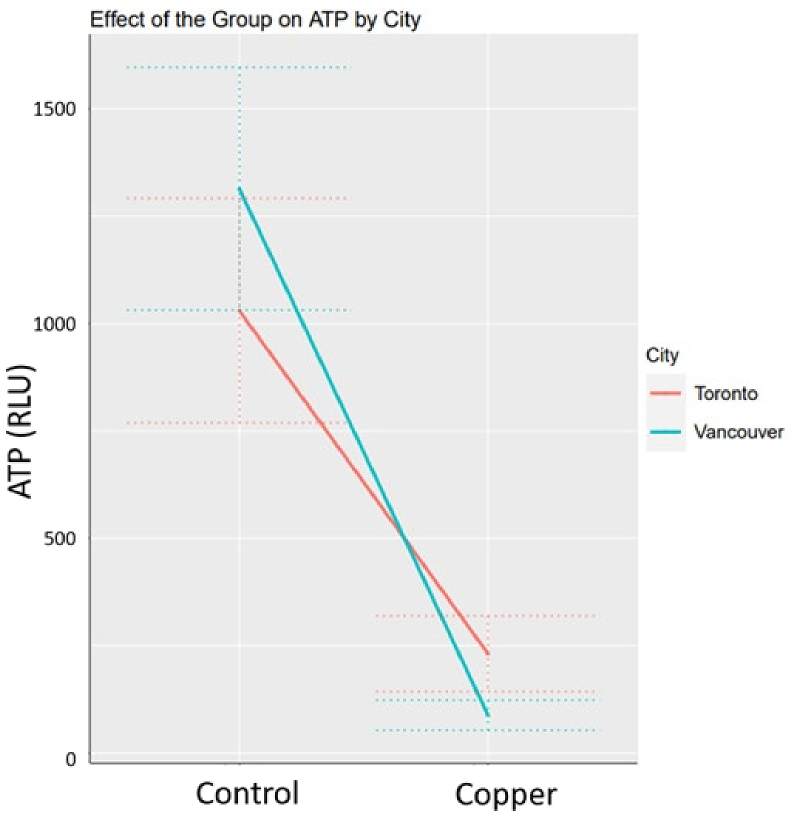

Figure 9: The effect of Cu compared to the control stanchions on the ATP RLU counts after 12 months of in-vehicle use

7.1.3 Lab Testing Results:

Figure 10A illustrates the accumulative results of all Cu products compared to the untreated controls. All Cu products showed excellent antiviral efficacy against the norovirus and coronavirus surrogates after two hours, regardless of disinfectant used in the 200-rounds of simulated cleaning or with the application of artificial sweat. Cu products killed on average 97.5% of the coronavirus surrogate by two hours with most of the antiviral activity occurring within the first hour. The human norovirus surrogate had a slower time-kill kinetic but demonstrated a 99.5% reduction in viral activity after two hours of exposure. This was consistent for all Cu products.

For bactericidal analysis, coupons were inoculated with *P. aeruginosa* or *S. aureus* in a range of 3.8-4.3 x 10^7 CFU/mL in a simulated soil inoculum. For *P. aeruginosa* the inoculum was collected at 30 minutes and one hour as Cu is known to be most efficacious against gram-negative bacteria. *S. aureus* is a gram-positive organism that is more resistant to Cu and therefore samples were collected at one and two hours. After one hour of Cu exposure 99.9% of *P. aeruginosa* was killed compared to the control (Figure 10B). Time-kill kinetics were slower for *S. aureus* however, after two hours between 89.9-99.9% of bacteria were killed for the various Cu products (Figure 10B). Synergy (enhanced bacterial killing) was observed with some disinfectants for both bacteria. The decals exhibited a higher killing efficacy with the AHP cleaner, and the Cu coating with the Quaternary ammonium disinfectant (individual data not shown).

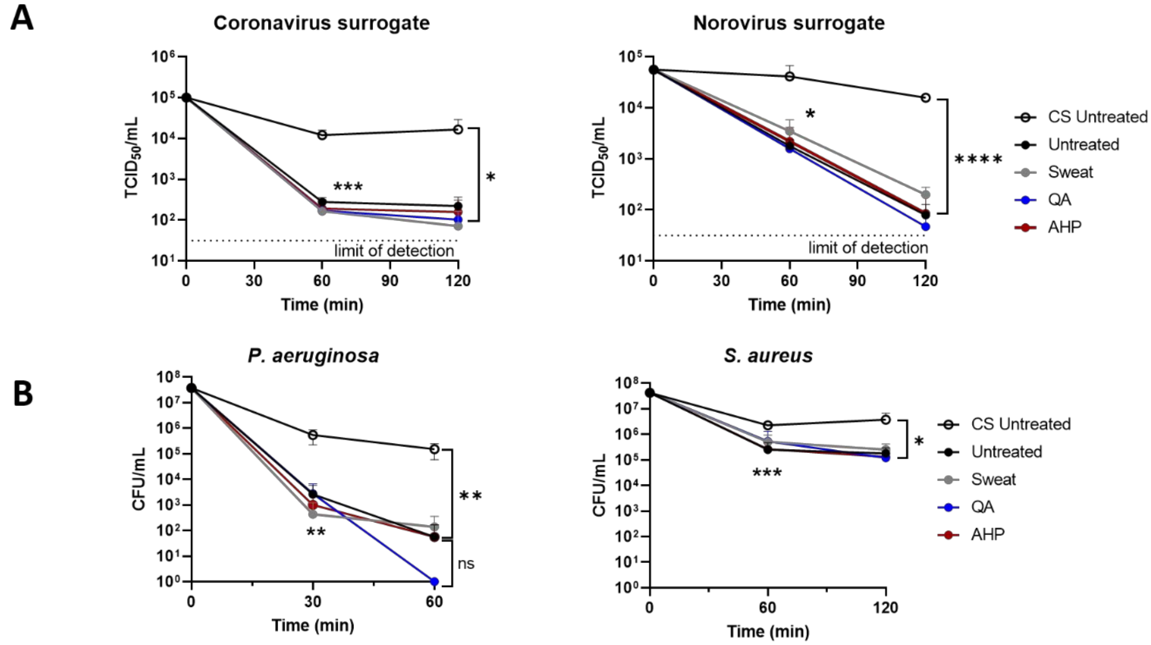

Figure 10: Persistence of A) Coronavirus and Norovirus surrogate viruses and B) *P. aeruginosa* and *S. aureus* after 1 year of simulated use with disinfectants and artificial sweat compared to untreated copper coupons. (CS: yellow painted carbon steel; QA: quaternary ammonium disinfectant; AHP: Accelerated hydrogen peroxide disinfectant)

7.2 Durability Assessment (Does it last?)

7.2.1 Monthly Durability Audits:

While both the Cu coating and Cu cover handled the abuse of daily transit better than expected, with no test points requiring replacement during the 1-year period, the Cu decal did have significant issues with vandalism. Over the length of the trial, 20 decals had been vandalized by passengers picking at the seam in an attempt to remove it. A high strength glue was added to the decal seam part way through the trial to reduce vandalism; however, incidents continued to occur.

Once the decals had been damaged, they would be left with an exposed sharp edge, see Figure 11 below. TTC decided to remove all Cu decals from vehicles in March 2022, halfway through the trial, as the sharp edge and frequency of vandalism in Toronto presented a safety risk for hand injuries.

Figure 11: Copper decal vandalism

All products were noted to have some level of tarnishing over the trial period, with minor darkening of the surfaces. This is summarized in Figure 12 with the new products on the left and 12 months of use on the right.

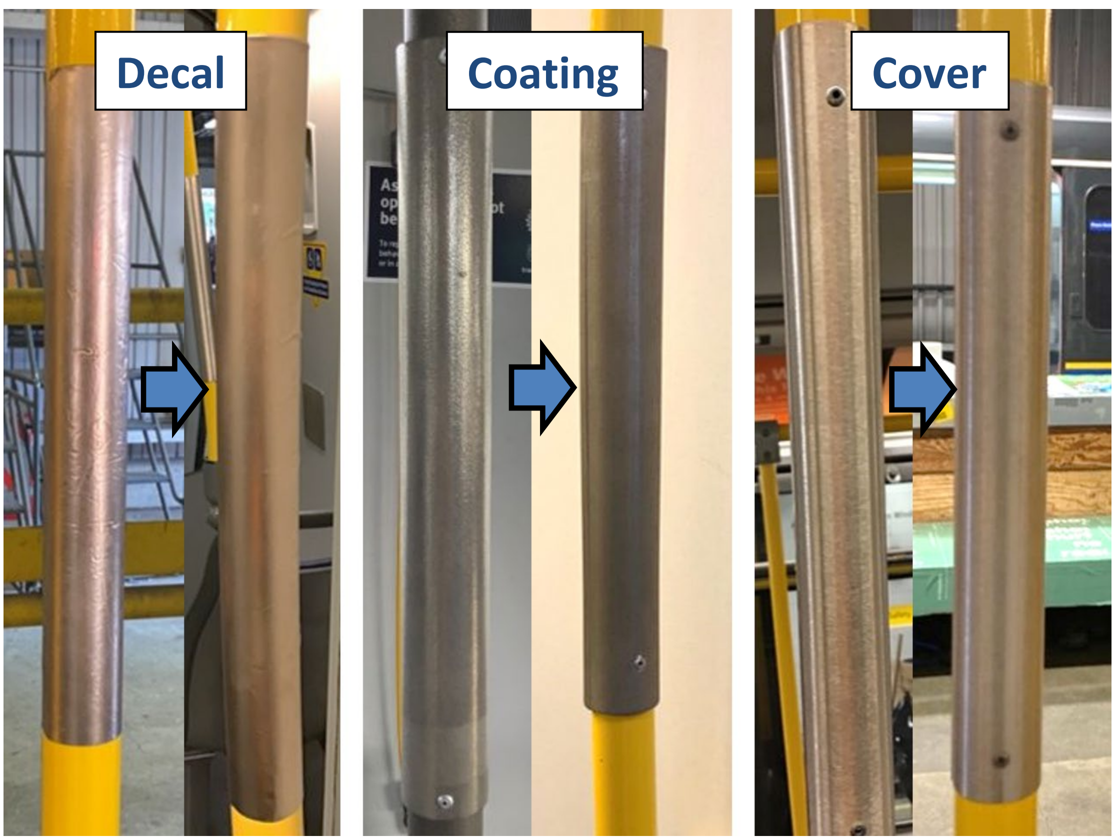

Figure 12: Copper products at new (left) and 12 months of use (right)

Figure 13 illustrates the evolving average surface Cu concentration over time for the three products installed. These measurements were acquired using the Waterloo Copper Concentration Kit[6], where a greater Cu concentration signifies a more pronounced release of ions from the product's surface. Notably, the Cu products situated within Vancouver's public transit network consistently display elevated concentrations in comparison to their counterparts in Toronto's public transit system. This variation can be ascribed, at least in part, to the relatively warmer climate and heightened relative humidity prevalent in Vancouver, conditions that facilitate the release of Cu ions.

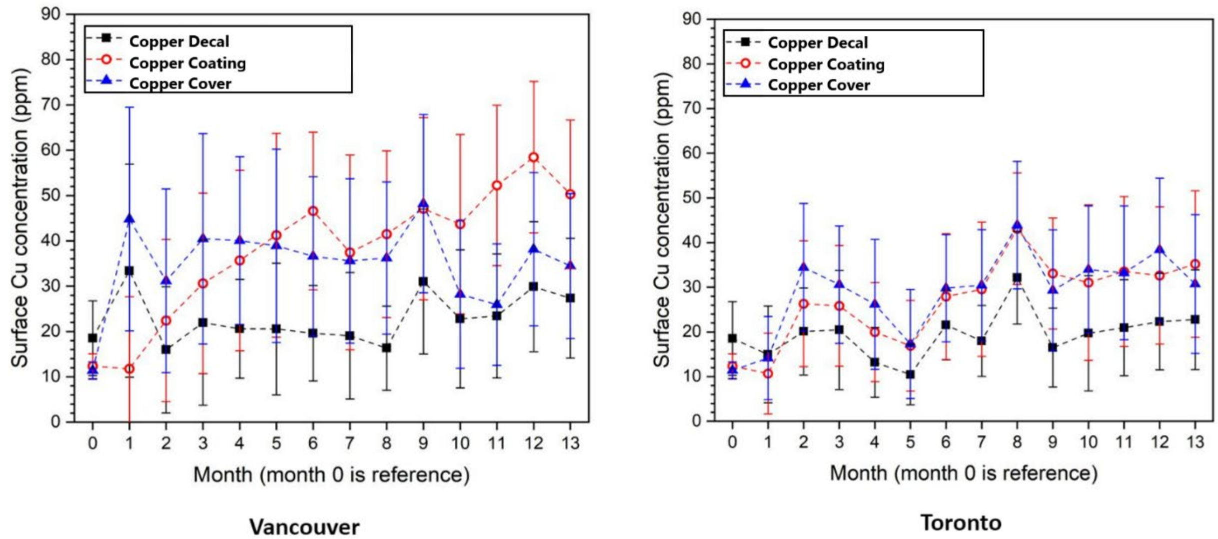

Figure 13: Average surface copper concentration for three different copper products determined from Waterloo Copper Concentration Kit

7.2.2 Six & 12 Month Durability Assessment:

Scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS) of the as-received Cu products, after 6 months, and after 12 months is shown in Figure 14 to Figure 17. Top-down SEM analysis showed a noteworthy presence of carbon-containing substances on the surface of all three products over time, as evidenced by the emergence of darker regions in the greyscale images. The carbon EDS maps (shown in yellow), showed carbon contamination in all Cu products after 6 and 12 months of installation, while the Cu EDS map (shown in red), revealed that surface blockage exhibited an initial spike but remained relatively constant throughout the year-long investigation.

This contamination displayed an uneven distribution, with a particular concentration within surface crevices and grooves. The existence of carbon contamination poses concerns, as it could diminish the effective Cu surface area, impacting Cu release mechanisms and, consequently, the long-term performance of the coating.

Complementary to top-down SEM analysis, cross-sectional SEM/EDS assessments of the Cu products indicated the copper product’s resilience. The analysis revealed no significant reduction in product thickness, suggesting the product’s long-term durability. Furthermore, EDS elemental cross-sectional analysis detected no indications of dealloying, reinforcing the stability of the Cu products even after 12 months of installation.

[6] (W. A. Anderson, 2021)

Colorimetry measurements showed a common phenomenon among all products, marked by a darkening of their appearance after their installation. This observable change in coloration is likely attributed to the oxidation of the Cu surface and the presence of carbon contamination.

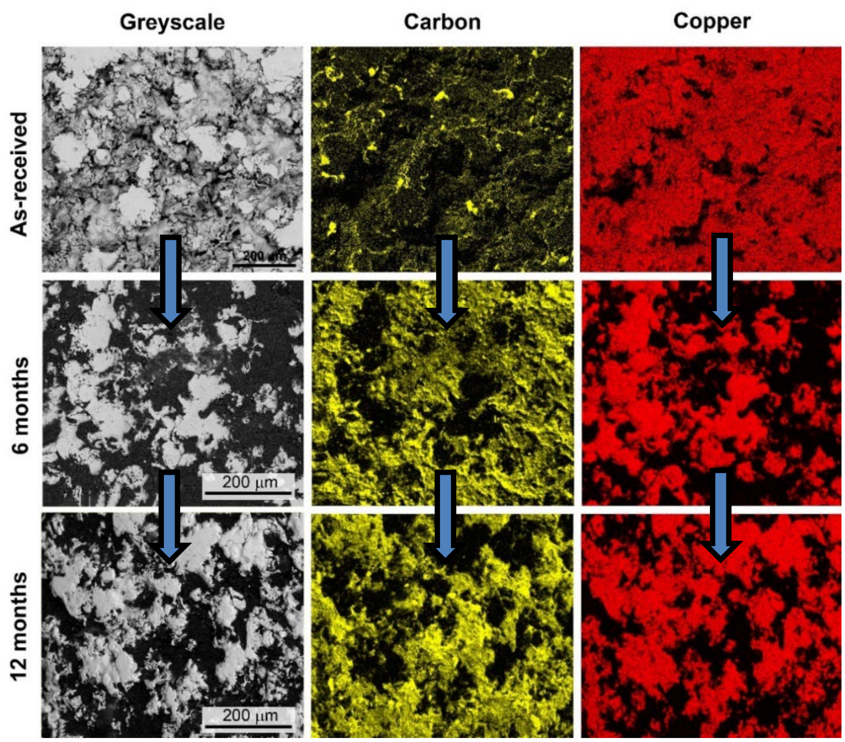

Figure 14: SEM/EDS analysis of copper coating on polymer surface[7]

[7] (Nakhaie & Asselin, 2022)

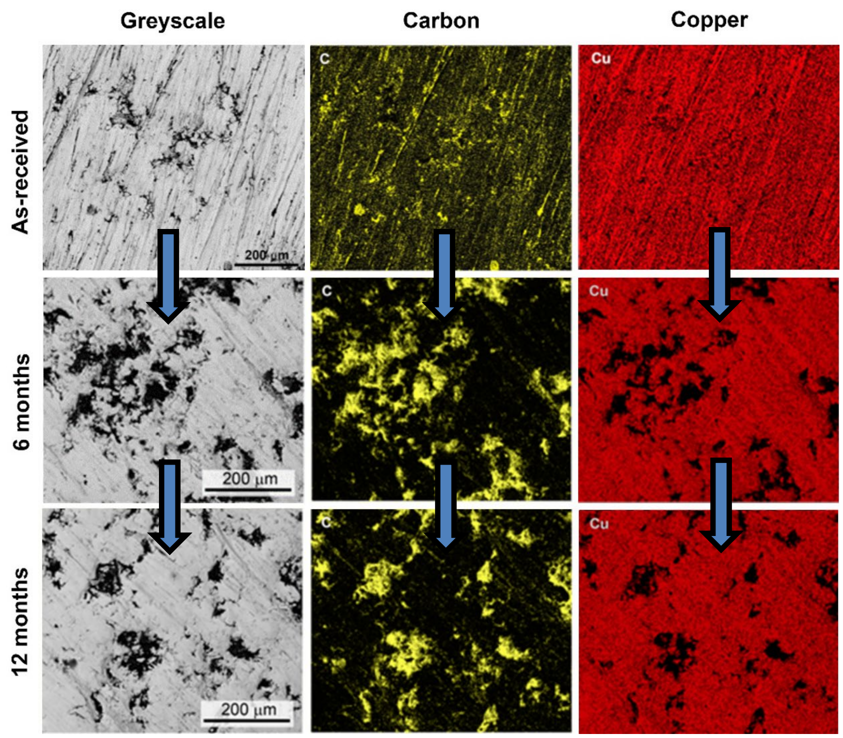

Figure 15: SEM/EDS analysis of copper coating on stainless surface

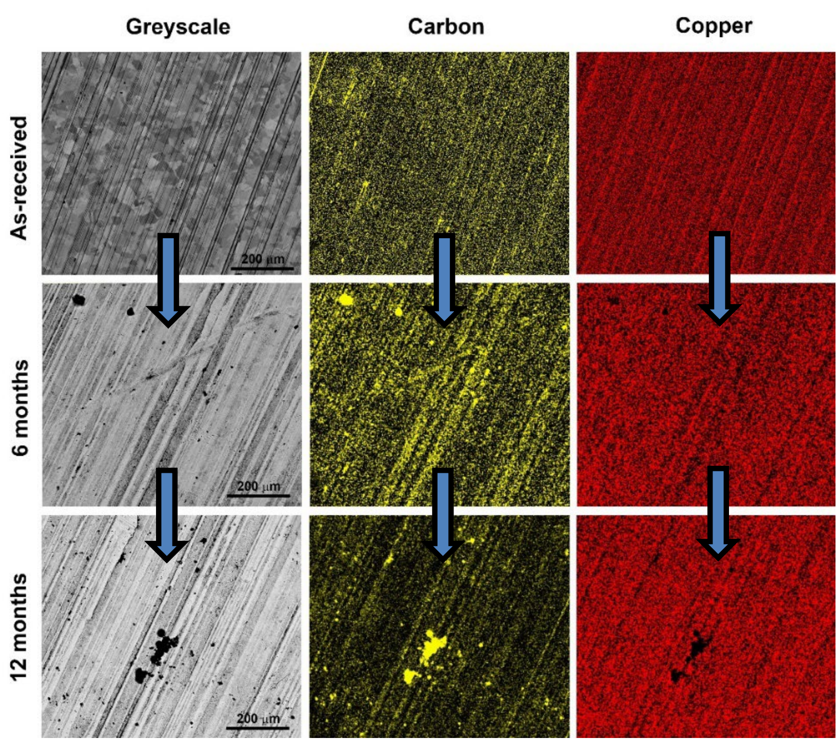

Figure 16: SEM/EDS analysis of copper decal

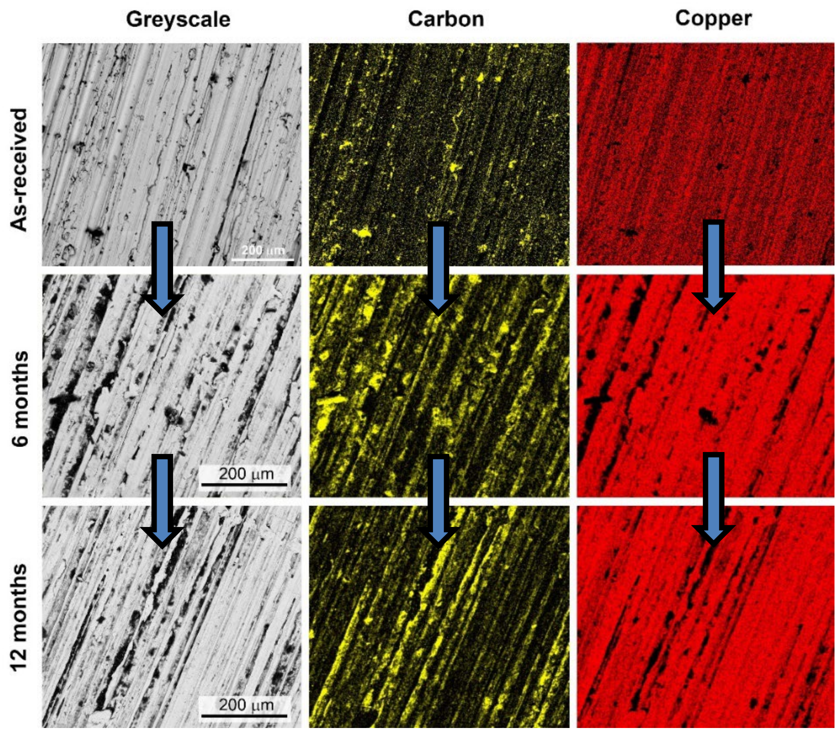

Figure 17: SEM/EDS analysis of copper cover

7.3 Public Survey (What do people think?)

The two-month rider survey had a total of 1,951 respondents: 838 in Toronto and 1,113 in Vancouver. In Vancouver 49% of respondents said they were aware of TransLink's copper pilot project, results of questions 2-4 are shown in Figure 18 - Figure 20.

An important consideration for these results is that they were collected during the COVID-19 pandemic. Public opinion around sanitization post pandemic may differ from the survey results.

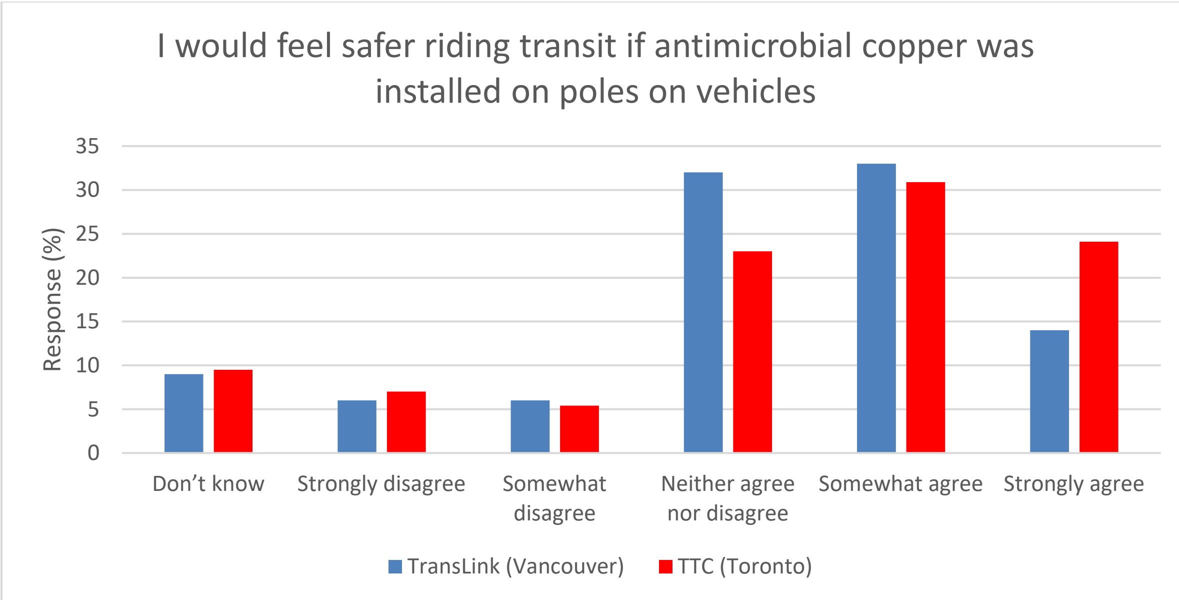

Figure 18: Public survey response question 2

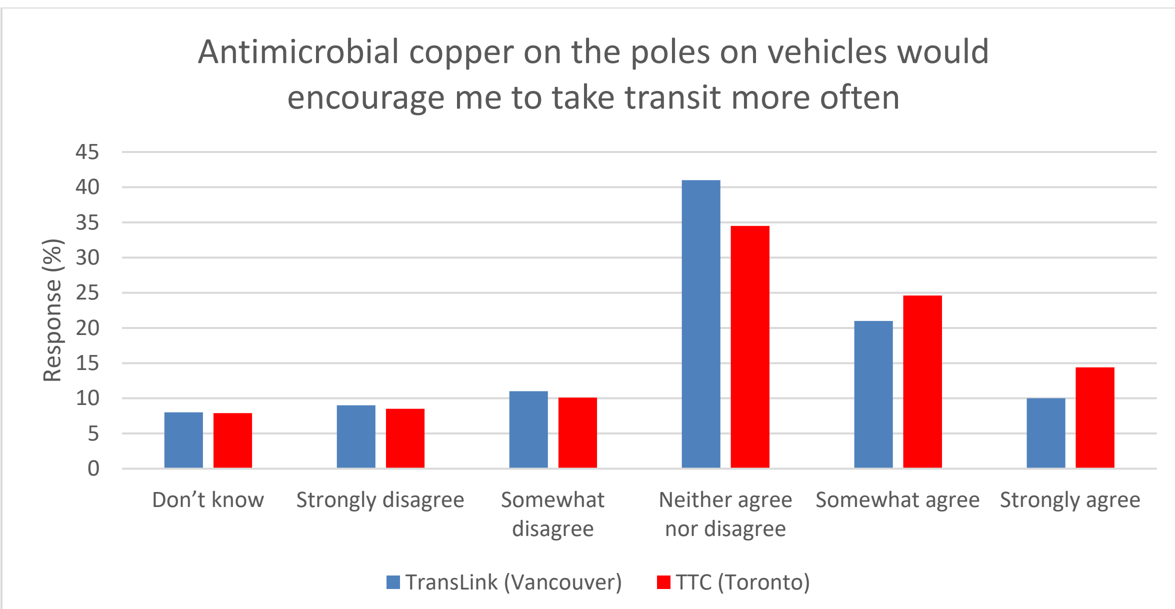

Figure 19: Public survey response question 3

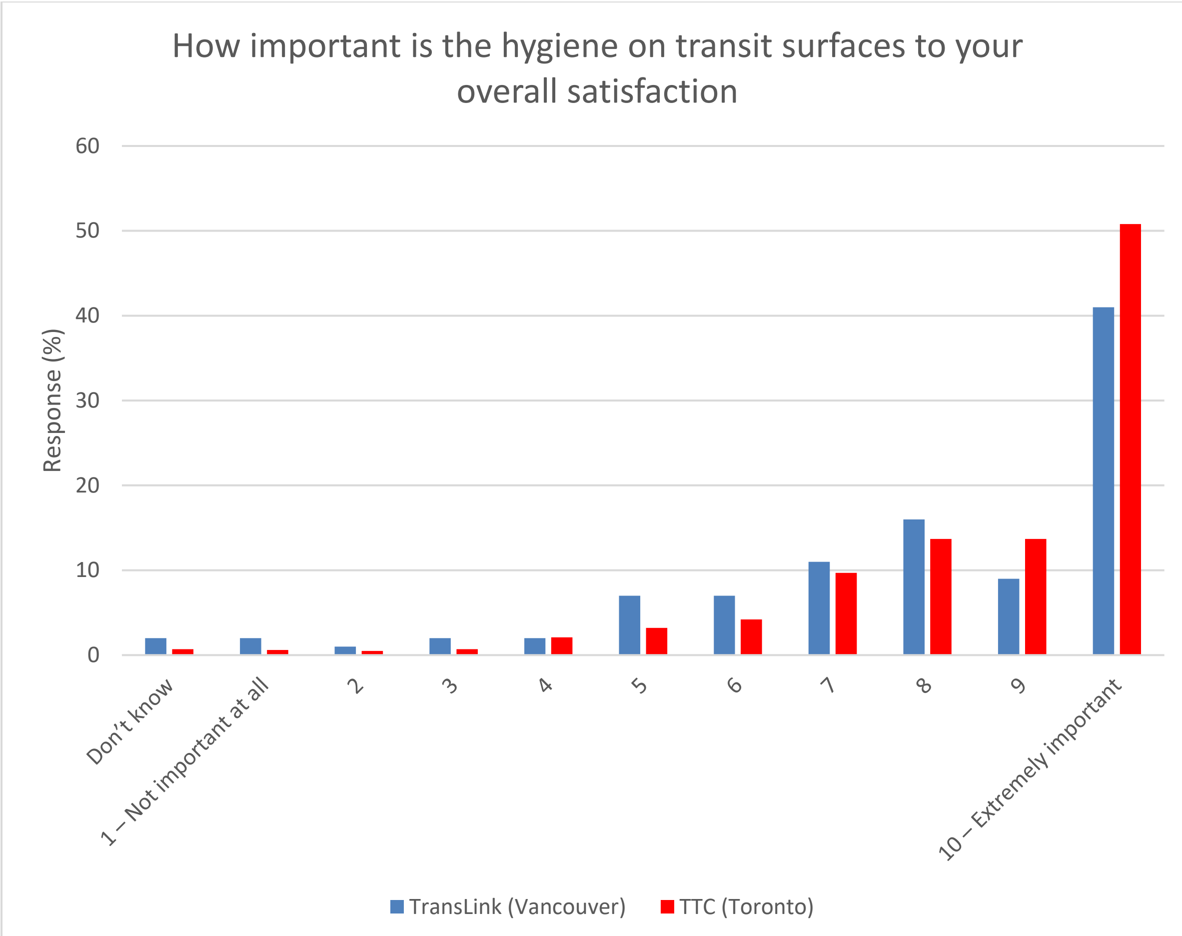

Figure 20: Public survey response question 4

The public opinion on the use of Cu in transit was moderately positive, while the importance of hygiene on transit surfaces was extremely important to the public in both Vancouver and Toronto. This discrepancy suggests that there is a knowledge gap for the public in how Cu could improve sanitization of surfaces.

If Cu was used in transit, there would need to be efforts towards public engagement. This would help to build an understanding of the improved hygiene on transit surfaces with antimicrobial Cu.

8.0 Unique Considerations

While the study was largely positive in the findings and results, there are some unique considerations for transit groups when considering antimicrobial Cu:

> Antimicrobial Cu is a tool for improving sanitization of surfaces, it is not a substitute for cleaning and disinfection. Cu can only kill pathogens if they are exposed to the Cu surface; if the surfaces are covered in dirt, the Cu cannot do its job.

Some transit riders can be allergic to the metals used in antimicrobial Cu alloys, most commonly to nickel. While there were no allergy issues noted over the course of this study, transit groups should still consider this risk when implementing antimicrobial Cu. It should be noted that allergies to Cu itself are extremely rare.

Cu products will discolor and tarnish over time. This will vary between products and can be as minor as a slight darkening in colour, see Figure 12, or something more significant such as a "stained" appearance.

Some products that have a distinct shiny "copper" look to them are more at risk of vandalism and theft in the transit setting. These products can be more eye catching and "expensive" in appearance despite their relatively low value. Some manufacturers may be able to alter the colour and sheen of their products to adjust for this factor.

Potential sharp edges should be considered and minimized when installing antimicrobial Cu products. During the study there were two sources of sharp edges: vandalized/pealing decals and poorly matched metal covers. While this was identified as a risk, there were no hand injuries reported during the study.

9.0 Conclusion

Antimicrobial copper was found to be an effective option for improving the hygiene of touch surfaces in transit. This was demonstrated through both on vehicle testing and in lab results. Along with positive antimicrobial efficacy results, the products were also found to be durable and resilient after 12 months of use. The products showed no significant reduction in thickness and had no indications of dealloying after extended use in transit.

The public survey revealed that hygiene on transit surfaces is extremely important to the public in both Vancouver and Toronto; however, it also indicated there may be a knowledge gap for the public in how copper could improve sanitization of surfaces. If implementing antimicrobial copper, there would need to be efforts in public engagement to improve awareness of the benefits.

While results were overall positive, there is no one size fits all as each product presented compromises for implementation:

Copper decals are inexpensive and easy to retrofit on existing assets but are susceptible to vandalism and damage.

Solid covers are easy to retrofit and resistant to vandalism, however they can be more costly.

Copper coatings are cost effective and resistant to vandalism; however, they can be difficult to retrofit on existing assets as components must be removed and sent for coating due to the specialized equipment.

Transit organizations looking to implement antimicrobial copper should consider these factors and select the most appropriate product type based on the application.

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