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大分工業高等専門学校年次報告

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〔研究論文〕

(educational research report)

STUDY ABROAD PROGRAMS FOR KOSEN STUDENTS - REFLECTIONS OF PAST AND PRESENT ENDEAVOURS

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Study abroad programs have always been a point of interest for students interested in foreign languages and cultures. Specifically for National Institute of Technology (henceforth referred to as Kosen) students, who are expected to become engineers that can flourish globally, unique study abroad programs are often found, linking with other engineering-related institutions abroad. However, since the COVID-19 pandemic in 2020, and border closures leading to a complete elimination of any international travel, getting back into the pre-pandemic norm is still taking time. This study will reflect mainly on a post-pandemic program, based on previous efforts, and what should be expected for future excursions.

Key Words **:** *study abroad, student motivation, international exchange, ESL/EFL, CALL*

1. INTRODUCTION

This study originates from an international exchange program between the National Institute of Technology, Oita College, originally referred to as Oita National College of Technology, now referred to more commonly as Oita Kosen. In the originally published Aoki et al (2009) report, details on an original international exchange problem were brought forward, and this program continued for almost a decade. The program developed over time to include an outbound program to Singapore Polytechnic, which started with one faculty and later expanded to unique programs across each of the engineering departments from Oita Kosen.

However, in preparation to this study abroad program, pre-departure orientation sessions were introduced. These orientation sessions were run by the English faculty, with the aim of increasing communicative competence of Kosen students before going abroad. The pre-departure orientation sessions were later expanded to include daily meetings and periodic reflections while on site, as described in the Ziemba (2016) study, explaining the detailed processes for study abroad programs that had evolved, to ensure student satisfaction and thinking about personal growth before, during, and after the programs. Oita Kosen then later developed a language-based study abroad program with the Ara Institute of Canterbury in Christchurch, New Zealand.

Originally starting in 2019 at the Timaru Campus, over a dozen students were taken to a rural city in which they had homestay experiences, farm visits, and even had the opportunity to teach about Japanese culture to local elementary school students. The high satisfaction rate at the time lead to the program to be renewed for the next year, however just days before departure in early 2020, the COVID-19 pandemic struck, and all overseas travel was forbidden, and the program cancelled at the last minute. Staff and students from both sides were clearly disappointed with the result, but nothing could be done given the state of the world at that time. With border closures and strict stay home policies continuing longer than originally expected, in early 2022, a renewal of the program was suggested and then approved even with the pandemic still being a significant source of concern.

This study will detail the processes of pre-departure sessions for this mid-pandemic iteration, daily efforts that were had on-site to ensure a greater learning outcome by the participating students, and how the students felt about the whole process overall. Now that the pandemic is no longer an active concern, it is hoped that the experiences throughout this study can be used in preparing future study abroad programs that can still be valid, even in case another pandemic may come forward, or other unexpected and unpreventable issues may arise.

2. METHODS

Although there were many steps and sources of concern throughout the preparation of the renewal of this study abroad program, for the purposes of this study, focus will be put on the pre-departure orientation sessions, the daily activities that were done throughout the duration of the program, and the final returnees presentation session. The pre-departure sessions were based on the original ones described in Ziemba (2016) based on the Overseas Study Program Guidebook developed by Toyama Kosen, which is unfortunately no longer in publication. Given that the majority of the 33 participating students in this program had never been overseas before, and thus had no passports to begin with, fundamental theories had to be introduced, such as culture shock. The participants had all heard of the term before but did not have an understanding as to how it works.

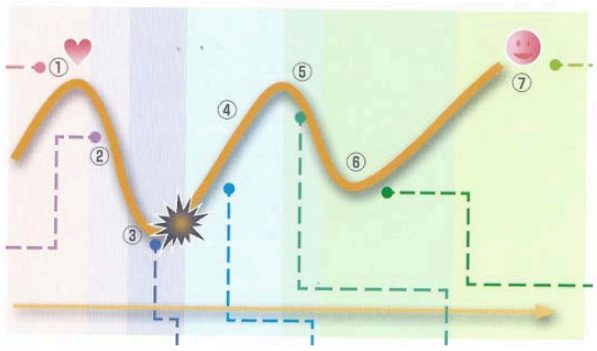

Fig.1 Culture Shock Timeline (emotion over time) taken from the "Overseas Study Program Guidebook" created by Toyama Kosen.

(1) Pre-departure orientation sessions

With the recruitment of students finalized over the summer vacation, including explaining the details of the program with the parents present, assistance from the designated travel agent was also a great support. The sessions were held once a month from October to February, with the departure being in early March, so only 5 sessions were able to be conducted in advance. Throughout these sessions, it was essential for the students to start by getting to know each other, as the participants came from various grades and engineering departments from the Kosen college.

Given that Kosen colleges are divided into 40-student classes from various engineering departments, the groups were set as four to five students purposely from different classes, with the participants ranging from first-year mechanical engineering students (15 years old) to fourth-year civil engineering students (19 years old).

October	Program overview, group ice breaking
November	Culture shock & having expectations
December	Group presentations on New Zealand
January	Placement test & survival English
February	Pre-departure final check & travel tips

Fig.2 P pre-departure orientation session schedule.

The first session in October had the aim of students to become comfortable with getting to know and work with people they have not before from within their own college. It is an important step to break down their initial barriers and hesitations within their peers before going overseas and doing similar activities with locals. The students were then tasked with preparing on their own time in groups, their expectations of the program, discussing what they were most worried about and how they could overcome it themselves, and with each other's' support, and finally a simple presentation in English about New Zealand itself, so that they can research in advance where they are going and pick up points of interest from their perspectives and share the information with the other participating students.

Throughout the sessions, participants were encouraged to become comfortable with by preparing to introduce themselves in English, be able to give simple responses to predictable questions they may get from locals about Japanese culture, and survival tips, such as how to stop a Japanese credit card if stolen while overseas.

The placement test was provided by Ara Institute of Canterbury, based off CEFR levels, and was conducted online in the form of a multiple-choice online test that students were able to do from their own smartphones or laptops. The results of these tests came back immediately and used to divide students into levels of which they would be studying together in on campus in Christchurch. Thanks to this activity, students knew prior to departure which one of their peers they would be taking daily classes with, regardless of their pre-departure orientation groups.

Finally, a detailed, pocket-sized travel plan booklet was created by and provided by the travel agent went into essential information that is often not considered by first-time overseas travellers, including customs regulations, and the declaration

of medicine and other restricted items that vary from country to country. The booklet included local emergency contact information, and detailed steps on what to do in case of emergencies, pages to write down the daily plans and any other notes of concern, and a page for the students to prepare an English translation of any dietary restrictions or medical concerns they may experience overseas that locals can refer to with a simple glance.

The most difficult part in conducting these pre-departure orientation sessions was the gathering all the 33 students at once face-to-face. Given that students were from various grades and faculties, scheduling conflicts would arise, and not all students were always able to come in-person to the sessions. Thankfully, the college had prepared early in the pandemic, a campus-wide broadcasting system, in which classrooms would have video recordings available on archive and able to participate in real time via Microsoft Teams as well, so in case students were not able to participate in-person due to illness, or had previous engagements, students were able to catch up on their own time, and still collaborate and communicate with their group members on demand using Teams as well.

(2) Daily activities while overseas

With the pre-departure sessions complete, daily communication was promoted as originally detailed in the Ziemba (2016) study, including daily meetings, and writing reflective journal entries. However, given the advancements in technology since that time and that students were all staying at various locations across Christchurch, students were required to make daily posts in a Teams group, including morning health checks, and diary entries. These acted like a group-restricted social media post, in which students must include a photo of something from that day, and write a detailed post, to which others were able to interact with and learn about their peers' experiences in real time as well. These posts were found to be useful to promote the program in real time, as the supervising staff chose some each day to be included in a daily update available on the school's website for anyone to see, including their class peers and their parents. This also helped because not all students kept in regular touch with their parents, and thus were able to see how their kids were doing through their posts updated daily on the school website, including reflections by the supervising staff in Japanese to explain in detail about some of the content brought up in the students' original posts.

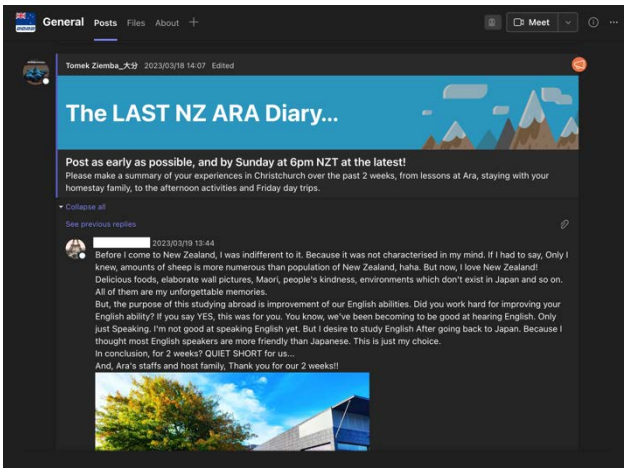

Fig.3 Example of a daily diary post by a student.

(3) Final presentation session by participants

Upon returning to Japan, students were encouraged to post no longer daily, but weekly reflections on how they felt after the program, how they have grown, what do they miss most, and what they plan on doing starting the upcoming school year to make most of their experiences to further enrich their future student lives. The session was originally planned to be held at the end of April, while the students' memories would still be fresh, and that the students who were not able to participate know more about the program and become interested in joining.

However, due to unforeseen circumstances, the session was delayed, but thanks to that was also refined in its content compared to the original plan of having some students present about their experiences. Students volunteered to give mini presentations in English, and the original creator of the program, who is now no longer at the Kosen, to come back and see how the program they developed has grown and give an inspirational speech about studying abroad. Parents of the participating students also were present to see their children present confidently in English in front of a crowd of people interested in hearing their stories, or also to participate the next time the program is offered.

At the end of this session, it was decided by the higher ups, for undisclosable reasons, that the program would go on hiatus, much to the chagrin of all the participants in the audience, but an online survey was also given out to the participating students, interested students, and parents of the participants to see how the program – from the original orientation sessions, to the daily journal entries and the final presentation session – could be further improved.

2. OBSERVATIONS AND RESULTS

The surveys this study was most concerned with was the participating student feedback, as well as the feedback from the parents/guardians of the students who participated in the study abroad program. The participant survey had 28 questions about the entire process, from reasoning to participate, their feedback on the pre-departure orientation sessions, how best to keep everyone on track while on-site, and how they expect to use this experience in their future endeavours. Out of 33 participating students, 23 responded (70% return rate) with the average time taken to complete the survey being over 50 minutes, which shows that the students took their time to seriously respond in detail to the 28 questions that were provided.

However, regarding the parents' survey, only 15 responded (45% return rate) to the 16 questions provided, but also had an average response time of over 27 minutes, which was shown by the detail provided in the free response answers given from the survey. Some specific details cannot be shared in this paper due to privacy concerns, but a generalization of the collected responses obtained was able to be made, that can be used for further improvements to the program and how it is run from the recruitment period to post-program.

(1) Survey feedback results – from parents

Starting with the parental feedback, the overall satisfaction rate of the entire program was at 100%, with 87% very satisfied and the remaining 13% satisfied. Parents detailed the creation and daily updates of the student diaries on the school website as the highest point of satisfaction, with the most common reasoning being that it was a way to check up on how the students were doing in real time, even if their children were 'too busy having fun' to contact their families via LINE with regular updates.

They also mentioned the comfort in having not one, but two of the English teachers that have taught their students previously accompany them on the program, knowing that they could contact the teachers directly in case of an emergency after having direct previous contact with them through the pre-departure orientation sessions and being the homeroom teachers of some of the participants.

Furthermore, most of the parents also mentioned a greater interest in learning English and wanting to explore other countries and cultures, with parents mentioning, for example, that their children were already studying Maori by themselves, or they have expressed interest in taking English certification tests, like EIKEN or TOEIC, without showing any interest in these kinds of activities prior to their participation in the study abroad program.

(2) Survey feedback results – from students

The student feedback however was thankfully a bit stricter. Most students mentioned they wished they had more pre-departure orientation sessions (once every two weeks instead of once a month), because they felt that they did not have enough time to prepare in advance mentally and linguistically. They also mentioned that they wished they had more information about the campus and city life in advance. There was one campus tour video provided after the online placement test, but the two accompanying teachers had not been to the campus or to Christchurch before, also taking into consideration that the previous 2019 iteration of the program was at the Timaru Campus and not the Christchurch City Campus. This will no longer be a concern in future iterations. Students, on average, claimed that it took them two to three days to get over their initial culture shock and become comfortable in living in a different country and communicating in a different language for the first time. This was shorter than the expected five-day time frame that was detailed in the pre-departure orientation session dealing with culture shock.

Most interestingly, they all enjoyed the daily diary entries conducted on Teams, stating that being able to see others' posts in English helped increase their reading comprehension and writing confidence, and being able to interact and react with each other's posts as a motivator for their future daily posts throughout the program. This is very reassuring because at first, much like in the original Ziemba (2016) study, the students felt annoyed and pressured to have to write something in English and submit it every day, but they grew to look forward to doing it and became intrinsically motivated to keep updating in more detail with longer posts as the days went on.

Finally, the students also mentioned how they were not sure how the returnees presentation session would happen, and that even only a small number of participating students were chosen or volunteered to present about their experiences in front of the large staff, peer and parent audience, they were reminded of their experiences on the program and wished they had volunteered to present as well at the session. In the future, individual presentations could be replaced by group presentations, based on their original pre-departure session groups, to give all the participants an opportunity for one last hurrah and

confidently present in English about their experiences.

The general audience feedback (those who were not participants, nor parents of the participants) showed a very great interest in participating in the program in future iterations and expressed great dissatisfaction in the final announcement at the end of the session that it would not be continued in the following academic year.

3. REFLECTIONS AND CONCLUSIONS

Humphreys & Baker (2021) conducted an interview-based study on Japanese students and their intercultural awareness development while on study abroad programs that focused on various locations and not just one. Regardless of the positive outcome of this study, it is not necessarily valid for study abroad programs in other locations that may be significantly culturally different from Christchurch, New Zealand, such as in Singapore, where the origins of this study are essentially based on. Mimicking of this study will be implemented in future study abroad programs with this Kosen, to see how further refine the study abroad process can be achieved in the long run.

Another source of consideration is the latest study by Tseng et al (2024) reviewing 42 studies from 1995 to 2019 that were meta-analyzed into hundreds of various effects in detail, including the balance of language learning motivators (assumed to be the main motivator for student participation in this program) and training sessions held in advance, much like in this study. Although the data does not cater specifically to Japanese students' L2 learning of English overseas, it reinforces the importance of long-term student feedback consideration.

Smith & Samuell (2024) also recently published research into Japanese higher educational intuitions' policies in study abroad programs from before and beyond the COVID-19 pandemic. With the Japanese government and Kosen colleges also focusing on the catch phrase of 'fostering the future of global human resources' as an ongoing goal, the study also focuses on the long-term implications of participating in study abroad programs, such as employment placement potentials after graduating participants conduct job hunting. These long-term aspects were not taken into consideration as part of this study but can be a great point of appeal for higher grade students in participation.

As mentioned earlier in this study, a greater online component in pre-departure sessions could help the students with their original culture shock and feelings of being overwhelmed upon arrival, regardless of how 'prepared' they were made to be. An interesting option would be like that introduced in the Hiroike & Yokomizo (2023) study, which had students from another Kosen (National Institute of Technology, Tokyo College) interacting with American university students online using Microsoft Flip. Students were able to asynchronously introduce themselves and get replies and interact with students halfway around the world from the comfort of their own smartphones. Given that Kosen students are all registered with Microsoft Teams accounts, the potential learning curve may not be as high as using other online interactive software and are more controlled than simply using social media services, such as Twitter or Instagram. Interacting with local Ara students and their Japanese club in advance can help give students a greater feeling of anticipation upon arrival, assuring them that they know someone locally in advance, and take away from the fear and hesitation the students felt at first going to their homestay families.

Although there is no guarantee that this exact Oita Kosen/Ara Institue of Canterbury will continue annually from now on, having the option to still conduct online international exchange programs regularly is a significant point of consideration. Furthermore, it can expand the possibilities of other institutions to study abroad with by starting with online, asynchronous student interactions to further promote cross-cultural understanding without even having to step on a plane, let alone leave their college campus or even their own homes. This field is currently in high demand for further research and expansion, and similarly envisioned studies are intended to be conducted in the near future. Concurrent iterations of this New Zealand study abroad program will incorporate a more detailed and concrete pre- departure program and further long-term support post return to maximize benefits of participating in study abroad.

Unfortunately, it seems that the new ongoing trend is to fully leave the planning and responsibilities to a travel agent, taking off the burden of responsibility and other tasks from the schools and their staff, and having an agent travel with the students. However, these kinds of programs, as intriguing as they may be for those in management positions, cannot guarantee educational value and significant reflection in students, as these travel agents are not educators. These programs are not simply overseas tours – they are opportunities for students to formatively change their lives even while on site. This 'easy out' trend must be avoided.

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（教育研究報告）

大分工業高等専門学校における主権者教育について
—2023年度「選挙制度講演会」の記録—

内田　龍之介

一般科文系

キーワード：主権者教育，政治教育，政治的教養，模擬投票

１．はじめに

主権者教育の重要性は，2015年の法改正で選挙権年齢が18歳に引き下げられたことを契機に増している．文部科学省と総務省による副教材である『私たちが拓く日本の未来』では，選挙制度や選挙の実際について解説されているほか，ディベートや模擬投票も案内されている．他方，これまでの主権者教育は政治的中立性に過度に配慮していたとされ，その転換を求める意見もある．

主権者教育の目的は何か．若者の政治離れを示すものとして投票率の低さがよく挙げられる．国政選挙における20歳代の投票率は1990年衆院選の57%以降，30%から40%台で推移していた．10歳代の投票率は，2016年参院選にて45%であったが，その後は低下傾向にある．他方，山田（2016）が整理するように，投票以外にも，請願書への署名，政治資金の寄付，ストライキなど政治参加には様々な形態がある[1]．年齢が上がるにつれて社会との接点が増え，知識を蓄積することで，政治参加が自ずとなされると考えられている．しかし，松林（2023）が「低投票率は投票という大切な政治的権利を行使する有権者の数が減っているという問題だけでなく，政治的不平等や政策形成の歪みを示唆する問題」[2]と述べるように，若者の消極的な政治的態度は，若者以外の意向が政治に重視されるという構造をもたらす．後述するように，主権者教育あるいは政治教育の目的は，投票率の向上に留まらず，政治への関心を誘い，思考させ，行動に移させることにある．

筆者が勤める大分工業高等専門学校（以下，大分高専）は工学を主体とする学校である．社会科学系学部のようなカリキュラムではないものの社会科関連科目を展開している．大分高専では授業に加えて，選挙権年齢に達する前の２年生を対象に，年に１度の選挙制度講演会を行っている．本稿は，2023年度の講演会の記録を示すことを目的とする．また，まずは主権者教育のあり方や実践例を整理し，講演会の課題や今後実践されるべき内容にも言及したい．

２．主権者教育のあり方

(1) 定義

主権者教育について，教育学の分野からは川原（2024）の定義を取り上げる．まず次のような問題意識を述べる．すなわち，これまでの社会科や公民科での主権者教育は政治や民主主義の知識を理解させることを重視し，若者が主権者である自覚を促してこなかったという．学校現場では，教育基本法により政治的教養を身につけることが必要とされつつも，学生運動を抑圧する経緯から政治的な事柄について慎重に扱う傾向にあった．しかしながら，今後は政治的知識に留まらず，現実の政治的現象に対して思考できるような教育が必要と説く．そのうえで，「主権者教育とは，自分たちが生まれながらに基本的人権や参政権をもっている『主権者である』ことに気づかせ自覚させる教育であり，18歳になって選挙権を持つ有権者となった時に，この権利をきちんと行使できるような主体である『主権者になる』ために必要な力を身に付けさせる教育」[3]と定義する．

政治学では，新藤（2016）が選挙権年齢の引き下げを契機に改めて現実政治の問題に提起することの必要性，政治的教養を養う教育を主張する．ただし，「政府（文科省）主導の『主権者教育』は，政治や社会の動きの文脈を考え行動することから若者たちを遠ざけようとするものである」[4]と指摘する．大学入学試験に向けて断片的な知識を記憶させるのではなく，「政治的教養をゆたかにするのが『主権者教育』の目標ならば，その基本は政治・経済・社会のありかたを考えさせる教育であるべきだ．『政治的中立性』や『中立かつ公正』な教育の強調は，主権者としての意義や認識を深めるものとはいえない」[5]とも述べる．具体的な提案としては，各年度予算額推移の把握，地域の多様な団体との交流，自治体との討論などを示している．

(2) 実践例

主権者教育を行うに際しては政治の知識を授けるだけ

でなく，学生に考えてもらう必要があることが認識されたが，そうした思考力を効果的に養う方法を紹介する．例えば宮下（2023）が重視するのは学校民主主義を通じた教育である．長期間変更されない学校規則は「ブラック校則」として問題視されることがある．そこで，高校における制服やアルバイト，授業に関するルールを，生徒会，教員，保護者の三者が建設的に議論し，改定に至った３校の事例を紹介した．こうした見直しを求める生徒の参画はこども基本法などに根拠があり，「その効果は何よりも生徒に必要とされている議論する力などの能力が向上していること，また主権者を育てる教育になっていることが明らかになっている」[6]という．

川上（2016）は「主権者教育というのは，自分自身と政治が関わっていくために必要な知識や技能などを習得する教育のことを指す」[7]と述べたうえで，争点の違いを示す新聞記事の活用や模擬投票を実例に挙げる．とくに模擬投票については玉川学園高等部の取り組みを担当教員に聞き取りながら紹介している．ボートマッチの活用，本物の投票箱を用いた投票の体験などには，政治を自分のこととして考える，争点を設定する，投票を習慣化する，議論が活性化するといった効果があるとし，その普及を提案している．

高専での主権者教育については次のような研究がある．川畑・佐藤（2019）は模擬裁判員裁判の実践とその効果を考察している[8]．とくに現実政治を扱ったのが加藤（2017）である[9]．具体的には，選挙管理委員会による講演，過去の国政選挙を想定した模擬選挙に加えて，高学年の授業では市議会見学や陳情が試みられた．受講生は実際の選挙でも票を投じたようであり，それらの有効性も確認されたと分析した．

芥川ら（2018）は，18歳選挙権の実施時期に合わせて新居浜高専など４校の学生に質問調査し，高専生の主権者意識を明らかにした．2017年衆院選に投票した学生の割合から，高専生は投票に対する意識が若干高く，18歳選挙権に概ね肯定的であるとする．また，「高専生は日常生活の安心感・安全性に直結する政治的課題に興味をもち，特に各政党がこれらの問題に対してどのような政策を立案しているのかについて，新聞・テレビ番組・ウェブサイト等を情報源として投票していることが分かった」[10]とあるように，高専生の関心を具体的に考察する．他方，回答を統計的に分析し，学年の違いを意識した授業計画が説かれていた．

濱井ら（2018）は４つの高専において法学，国際関係論，政治学などの知見を応用した授業の事例をまとめている[11]．とりわけ政治学の授業に関しては，選挙制度，投票行動に関する基礎的な指導案が示されたほか，メディアリ・テラシーに関する講演を新聞社と行った事例が述べられていた．

村上（2016）が想定するのは大学の教養課程や入門レベルの政治学であるが，授業で扱うべきテーマを具体的に示す[12]．そもそも政治学には社会の統合，投票率の向上，活発な政治参加という実践的な目的がある．受講生がその目的を達するためには，批判的精神を養う必要から多元的民主主義，例えば権力分立の歴史やポリアーキーをテーマにするといったことを提案する．また，投票に際しては主要な政党間，候補者間の差異を認識して論理的に考える必要があることから，政党システムもテーマに据えるべきという．授業では中立性や多元性にも配慮する必要があるが，現実政治を形作る見解や立場の対立を知らせ考えさせる教育が実践されるべきと主張している．この示唆は高専の上位年次向けの科目に応用できよう．

このように，主権者教育において行うべきことは多岐にわたる．テキストを用いて単に政治制度についての座学を行うだけでなく，学校や社会での実際的な課題を事例に模擬投票やグループワークを取り入れることも必要である．政治的意思を示せるようになるには，授業にて積極的に政治現象を扱うこと，その背景を分析し意見を保持できる思考力を養うことも重視しなければならない．高専には有権者の年齢に達した学生が多くいることから，入門から応用に至る内容も準備するべきであろう．

３．大分高専における事例

(1) 講演会までの経緯

従来，大分高専の選挙制度講演会は，２年生の各クラス担任が『私たちが拓く日本の未来』を説明することで実施されていたようである．2023年度は社会科教員が２年生全クラスを対象に講演する方式となった．具体的に講演会は，選挙制度として小選挙区比例代表並立制を説明すること，４学科の学生から立候補者を募り，公約を掲げてもらうこと，２年生の学生を有権者と想定して投票することを計画した．

小選挙区比例代表並立制を対象とした理由は，講演会が開催される時期（2023年12月20日）が，既に第49回総選挙（2021年10月31日投開票）から２年を経過し，任期の折り返しがなされていたことにある．また，筆者は２年生対象の通年科目（政治・経済）を担当している．前期の授業では衆議院の解散を扱い，日本国憲法第７条による解散が直近に行われる可能性を説明していた．しかしながら，選挙制度については触れられなかったので，講演会を制度解説の機会とした．

主権者教育は学生が現実の政治現象を思考するようになることが一つの目標である．講演会は選挙制度に関することであるから，小選挙区制の理解に重点を置いた．ただし，模擬投票では，実際の候補者や政党の公約集を用いなかった．これは授業にて日本の政党システムやイデオロギーなどについて言及できなかったことによる．そのことか

ら，学校を争点とした．講演会開催前に学生会（高校等の生徒会に相当）が会長選挙を行い，今後の学生会のあり方を問うていた．最多得票者が当選するという仕組みを身近に体験してもらうべく，講演会の模擬投票のテーマは今後の大分高専にしたのである．

定期試験の日程を考慮し，後期中間試験の終了直後（12月11日）から，講演会にて模擬投票を行うこと，選挙のテーマが「大分高専で○○を実現します」であることを案内した．８名の学生が立候補を届け出て，表２のような公約を掲げた．８名の内訳は，男子学生が６名，女子学生が２名である．学科別では，機械工学科から２名，電気電子工学科から３名，情報工学科から１名，都市・環境工学科から２名となった．各候補者の氏名，クラス，公約は講演会に先駆けてMicrosoft Teams上にある２年生全体用の欄に掲示した．

⑵ 講演会の内容

表１　2023 年度選挙制度講演会の流れ

内　容		時間
制度説明	①制度の説明 : 小選挙区と比例区の定数，議席配分の方法，2021 年衆院選での大分と九州ブロックの結果 ②投票までの流れ : 投票の案内，投票の仕方，投票済証の収集と活用法，出口調査など選挙関連のアルバイト ③選挙運動の流れ : 候補者の一日，選挙カーでの活動，選挙事務所の運営，応援弁士の名フレーズ	15 分
模擬投票	①ルール説明 : 模擬投票の流れ，講演会参加者全員での頑張ろうコール ②演説会 : 各候補者による２分程度の演説（演説順はくじ引きで決定） ③投開票 : Microsoft Forms を用いた投票と開票 ④結果 : 投票数の開示，当選者の感想，当選者を中心に全員での万歳三唱	25 分
解説	①制度が与える影響 : デュヴェルジェの法則，小選挙区制がもたらす結果，各国の特徴 ②投票行動 : 人は何を基準に投票先を決定するのか，日本の有権者の分類 ③若者と選挙 : 投票率の推移，若者の投票率の低さの理由とそれがもたらす影響	10 分

講演会は次のように進められた．第一に制度の説明と選挙の実際である．まずは副教材の内容を踏まえ，小選挙区と比例区の投票や議席配分の仕組み，2021年衆院選での大分県内各選挙区と九州ブロックの結果を説明した．選挙の実際は過去の様々な選挙での立候補者と有権者の行動を題材にした．有権者に関しては選挙案内の郵便物，投票の仕方，投票済証，選挙関連のアルバイトなどを，立候補者については選挙期間中の１日の流れ，学生も知るであろう政治家の演説でのフレーズを筆者の撮影した写真や体験も示しながら説明した．単なる制度の説明では関心が高められないと考え，実際例を多用したのである．

第二に模擬投票である．模擬投票は時間の制約上，小選挙区のみを想定し，１名が当選すると説明した．候補者の演説，Microsoft Formsを用いた投票，開票結果の掲示の順で行われた．なお，票数は表２の通りとなり，当選者と次点の票差はわずか１であった．獲得票数や割合に関わらず，最多得票者が当選するという小選挙区制の仕組みが，この票差をもとに理解できたであろう．

表２　各候補者の公約と獲得票数

各候補者の公約のキャッチフレーズ	票数
A: 学食と売店をキャッシュレス対応にします！	37
B: 高専の始業時間を遅くします！	36
C: 高専にカラオケを設置します！	29
D: アイスの自販機を設置します！	16
E: 高専を大分駅徒歩 10 分圏内に移転します！	10
F: 高城駅からシャトルバスを運行します！	10
G: 新 500 円玉硬貨を自販機と食券機に対応させます！	7
H: 女子の入学者割合を５割に増加させます！	4

投開票が終了し，解説編に移行した．まずは選挙制度が与える影響や法則である．模擬投票では８名が立候補したが，当選できるのは１名のみで，次点以下の７名の獲得票は死票となった．有権者には自らが投じる票を無駄にしたくないという心理がある．次回からは考え方の近い当選見込みのある政党・候補者に投票するようになるだろう．下位の政党・候補者は不出馬となり，結果的に政党・候補者の数が減少する．また，「小選挙区制は二大政党制をもたらす，比例代表並立制は多党制をもたらす」というデュヴェルジェの法則を説明した．実際，単純小選挙区制を採用するアメリカやイギリスでは二大政党制が定着していること，日本でも有効政党数が減少した時期があることといった例を示した．このように，選挙制度は単にルールを定めるだけでなく，結果に作用することを解説したのである．

今後，有権者として何を基準にして投票するべきなのか，について政治学の授業で扱う理論をわかりやすい言葉や事例に置き換えて説明した．次点となった学生は、その所属クラスが候補者を１名に集約したので，当選可能性の高い候補者であった．一方，当選者のクラスからは３名の学生が立候補していた．最終的に候補者の多いクラスの学生が当選したが，なぜ意外な結果となったのか．学生が投票の際に重視したかもしれない要素として，公約内容，クラ

スや部活，学生寮といった人間関係，見た目や話し方，立候補者の普段の成績を挙げてみた．クラスといった仲間意識を重視した者は政党帰属意識が，公約を重視した者は争点態度が，高い成績の維持を重視した者は業績評価が作用して投票先を選択したと分析した．投票行動の理論を身近な例に例えたことが工夫点である．

最後に投票率についても言及した．インターネット選挙が解禁され，選挙権年齢が引き下げられたものの，国政選挙における投票率が低下傾向にあること，とくに10歳代や20歳代の投票率が全体の投票率を下回る現状と理由を解説した．投票は義務ではないが，小選挙区制の仕組み上，わずかな票差で当落が決する場合がある．政治や選挙に関心があっても棄権した場合には，当選してほしい候補者の落選や，相応しくないと考える候補者の当選を誘発してしまう．また，結果として若者の意向が政治に反映されないことにもなる．先に述べた投票基準の設定は自由であるから難しく考えず，来るべき選挙ではまずは可能な範囲で情報収集してみることを呼びかけた．

４．おわりに

2023年度の選挙制度講演会には次の効果が考えられる．第一に制度の理解である．小選挙区制に限定したが，１名のみ当選できる制度や効果が実際例や体験を通じて認識できたであろう．

第二に学校活動の活発化を期待したい．大分高専ではクラス替えがなく，学科の枠を超えた交流が難しい場合がある．実際，筆者が校則の変更などを問いかけても，学生から積極的な姿勢は示されない．学生の控えめな側面を感じていたが，模擬投票では複数の学生が学生会を率いたい旨を述べていた．これを機に学校全体を見渡すような活動がなされると，講演会の意義がみいだされることになる．学生には大いに微視政治を体験してもらいたい．

ただし，新藤（2016）は，学校運営などをテーマとする模擬投票や立会演説会を行うといった公民科教育について，「模擬投票などを中心とした『主権者教育』は，『投票ごっこ』といえば戯言とのそしりをうけるかもしれいけれども，このレベルにとどまっていてよいのだろうか」[13]と疑問を呈し，社会問題を扱うことを提唱している．今回の講演会では学校を例に模擬投票を行ったので，入門レベルの内容となったこと，現実政治を扱えていないことが課題として残った．大分県では2023年４月に県知事選挙と参議院大分選挙区補欠選挙が行われた．最多得票者が当選するという点でこれらの選挙や候補者を題材とすることは可能であり，とりわけ参議院補欠選挙では２名の候補が数百票差を争った．しかしながら，２年生の授業では地方自治や政党といった単元を扱えておらず，講演会のテーマに設定できなかった経緯がある．

今後は複数年にわたる計画的な授業と主権者教育を試みる．筆者は２年生，３年生，４年生，専攻科生の政治学関連科目を担当している．国あるいは大分県レベルの現実的な課題を授業，レポート，試験の内容に加味する．また，政治日程をみながら実際の選挙を題材に投票を行い，その効果も実証的に分析したい．とくに今回の講演会の対象であった学年については，４年生の選択科目にて改めて投票行動などの理論と実際に触れる予定である．地方自治も授業計画にあることから，県議会との連携なども模索することで，政治的争点のさらなる理解や体験的な政治参加を図りたいと考えている．

注

1) 政治参加の形態については，山田真裕（2016）『政治参加と民主政治』東京大学出版会，41～51頁参照．
2) 松林哲也（2023）『何が投票率を高めるのか』有斐閣，187頁．
3) 川原茂雄（2024）「主権者教育とは何か」，川原茂雄・山本政俊・池田考司（編）『主権者教育を始めよう』明石書店，19頁．
4) 新藤宗幸（2016）『「主権者教育」を問う』岩波書店，56頁．
5) 同上，37～38頁．
6) 宮下与兵衛（2023）「日本の生徒参加による主権者教育は今」，荒井文昭・大津尚志・古田雄一・宮下与兵衛・柳澤良明『世界に学ぶ主権者教育の最前線』学事出版，41頁．
7) 川上和久（2016）『18歳選挙権ガイドブック』講談社，107頁．
8) 川畑弥生・佐藤勇一（2019）「模擬裁判員裁判を用いた福井工業高等専門学校における主権者教育の試み」，『福井工業高等専門学校研究紀要　人文・社会科学』（第53号）を参照．
9) 加藤博和（2017）「高専社会科を通じた模擬選挙・主権者教育の実践」，『日本高専学会誌』（第22巻第2号）を参照．
10) 芥川祐征・佐伯徳哉・濱井潤也・高橋祥吾・小川清次・手代木陽・鹿毛敏夫・平野淳一（2018）「選挙権取得段階における高等専門学校学生の主権者意識の特徴と課題」，『新居浜工業高等専門学校紀要』（第55号），10頁．
11) 濱井潤也・佐伯徳哉・小川清次・鹿毛敏夫・高橋祥吾・手代木陽・平野淳一・芥川祐征（2018）「18歳選挙権導入期における主権者教育の試行的実践事例」，『新居浜工業高等専門学校紀要』（第55号）を参照．
12) 村上弘（2016）「政治学教育における目的，内容，方法」，『年報政治学』（第67巻第1号）を参照．
13) 新藤，前掲書，6頁．

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(archive)

Non-holonomic distributions and its extremals

Yumiko Kitagawa *

Abstract

A subriemannian manifold (M, D, g) is a differentiable manifold M equipped with a subbundle D of the tangent bundle TM of M. D is assumed a *non-holonomic* or *bracket-generating* distribution. We study some *non-holonomic distributions* and its *extremals*. The geometry on subriemannian manifold is very important as differential geometry and is closely related also to the control theory.

1 Introduction

This paper is a survey paper on subriemannian geometry and author's thesis [4] with related topics. We emphasize abnormal extremals in subriemannian geometry. The subriemannian geometry is very important in differential geometry and it is closely related to the control theory.

First of all we give a survey on the problem of length-minimizing paths and explain the abnormal exremals that does not appear in riemannian geometry but does in subriemannian geometry.

A subriemannian structure on a manifold M is a pair (D, g) such that D is a smooth distribution on M and g is a riemannian metric on D. A subriemannian manifold is a triple (M, D, g) such that M is a manifold and (D, g) is a subriemannian structure on M. In particular, if $D = TM$ then (M, D, g) is nothing but a riemannian manifold (M, g).

Riemannian geometry tells us that a minimizer between two points of a connected riemannian manifold (M, g) is a geodesic, provided that the curve is parametrized by arc-length, and the geodesics are characterized to be the curves satisfying the geodesic equation expressed in local coordinates as:

$$\ddot{x}^i + \sum \Gamma^i_{jk} \dot{x}^j \dot{x}^k = 0,$$

where Γ^i_{jk} denotes the Christoffel symbol. Conversely, every geodesic is locally length minimizing. In the formulation of symplectic geometry, the geodesics $x(t)$ are the projections to the base manifold M of the integral curves $(x(t), p(t))$ of the Hamiltonian vector field $\overrightarrow{E}$ defined on the cotangent bundle T^*M, where E is the energy function associated to the metric g.

Now in subriemannian geometry, it is also of fundamental importance to study minimizers between two points of a connected subriemannian manifold (M, D, g). Since the metric g is defined only on the subbundle D of TM in this subriemannian case, there is no canonical means to define the length of a general curve $\gamma : [a, b] \to M$. But we can well speak of the length of γ if γ is an integral curve of D, that is, if $\dot{\gamma}(t) \in D_{\gamma(t)}$ for all t.

On the other hand Chow's theorem tells that if M is connected and if D is nonholonomic (in other word, bracket-generating), then any two points of M can be joined by a piecewise smooth integral curve of D.

Hence, especially for a connected nonholonomic subriemannian manifold (M, D, g), it makes sense and is important to study the minimizers (length minimizing piecewise smooth integral curves) between two points of the subriemannian manifold (M, D, g). However, contrary to the riemannian case, this problem is very subtle, mainly because the space $C_D(p, q)$ of all integral curves of D joining p and q may have singularities, while, in the subriemannian case, the space $C(p, q)$ of all curves joining p and q has no singularity and is a smooth infinite dimensional manifold, which makes difficult to apply directly the variational method to the subriemannian case.

For a subriemannian manifold (M, D, g) we define a *normal biextremal* to be an integral curve of the Hamiltonian vector field $\overrightarrow{E}$ associated to the Hamiltonian function $E : T^*M \to \mathbb{R}$, where E is the energy function associated with the subriemannian metric g. We then define a *normal extremal* to be the projection to M of a normal biextremal. Then, as in riemannian geometry, a normal extremal is locally a minimizer.

However, R. Montgomery ([7], [8]) and I. Kupka [11] discovered that there exists a minimizer which is not a normal extremal, and hence called it abnormal. The appearance of abnormal minimizers in subriemannian geometry is a surprising and peculiar phenomenon, which never arises in riemannian geometry.

If D is a distribution on M, then the annihila-

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tor bundle $D^\perp$, considered as a submanifold of the symplectic manifold T^*M, carries a (singular) characteristic distribution $\mathrm{Ch}(D^\perp)$. An integral curve of this characteristic system $\mathrm{Ch}(D^\perp)$ contained in $D^\perp\backslash\{\text{zero section}\}$ is called an *abnormal biextremal*, of which the projection to M is called an *abnormal extremal* .

A rigorous application of the Pontryagin Maximum Principle of Optimal Control Theory to subriemannian geometry shows that a minimizer of subriemannian manifold (M, D, g) is either a normal extremal of (D, g) or an abnormal extremal of D.

This was settled the long discussions that had been made until 1990's by many mathematicians with erroneous statements, and gave a right way to treat the problem of length-minimizing paths in subriemannian geometry. The difference between riemannian geometry and subriemannian geometry lies in particular on the existence of abnormal geodesics. It is known that abnormal geodesics are characterized as singular curves of so-called endpoint mapping in control theory (see Montgomery[8] and §9 of this paper). We will give a survey on the problem of length-minimizing paths mainly following Liu and Sussmann [6]. In the author's thesis [4], we studied homogeneous subriemannian structures, in particular, we classified homogeneous contact subriemannian structures. In our paper [3], we have studied cone structures which arise naturally from Cartan distributions, in terms of control systems. The usage of the notion of control systems enables us to clarify the duality of abnormal geodesics on subriemannian Cartan structures. Since control systems are generalizations of distributions, it is very natural to study homogeneous control systems and subriemannian structures on them, which will be treated in forthcoming papers.

2 Non-holonomic distributions

Let M be a differentiable manifold. A subbudle D of its tangent bundle TM of M of rank r is alternatively called a distribution on M of dimension r, since it gives a law which assigns to every point $p \in M$ an r-dimensional subspace D_p of the tangent space T_pM. A section of D on an open set $U \subset M$ is a local vector field X defined on U such that $X_p \in D_p$ for all $p \in U$. A local basis of D on U is a system of sections $X_1, \ldots, X_r$ of D defined on U such that $\{(X_1)_p, \ldots, (X_r)_p\}$ forms a basis of D_p for all $p \in U$. It is clear that for any point $p_0 \in M$ there is an local basis of D defined on a neighborhood of p_0. If $\{X_1, \ldots, X_r\}$ is a local basis of D on U, then any section X of D on U is uniquely written:

$$X = f_1X_1 + \cdots + f_rX_r$$

with some functions $f_1, \ldots, f_r$ on U, and we say that D is locally generated, or defined, by $X_1, \ldots, X_r$.

Let $D^\perp$ denote the annihilators of D, that is, $D = \bigcup_{p\in M} D_p^\perp$ with

$$D_p^\perp = \{\alpha \in T_p^*M; \langle\alpha, v\rangle = 0 \text{ for all } v \in D_p\}.$$

Clearly $D^\perp$ is a subbundle of the cotangent bundle T^*M of rank s, where $s = \dim M - r$. If $\{\omega^1, \ldots, \omega^s\}$ is a local basis of $D^\perp$, we say that D is locally defined by the Pfaff system $\{\omega^1, \ldots, \omega^r\}$ or by the Pfaff equations:

$$\omega^1 = \cdots = \omega^s = 0.$$

In this sense, a distribution is also called a differential system or a Pfaff system.

Given an r-dimensional distribution D on M, one of the most important problems that has been studied since the nineteenth century is to study integral manifolds of D. An immersed submanifold $f : S \to M$ is called an integral manifold of D if

$$f_*T_sS \subset D_{f(s)} \quad \text{for all } s \in S.$$

Evidently the dimension of an integral manifold is $\leq r$. However, it is not always the case that there exists an r-dimensional integral manifold.

Definition 1. *A distribution D of dimension r on M is called completely integrable if about every point $p_0 \in M$ there is a coordinate system $(U, (x^1, \ldots, x^n))$ such that all the submanifolds of U given by $x^{r+1} = \text{const}$, $x^{r+2} = \text{const}$, $\ldots$, $x^n = \text{const}$ are integral manifolds of D.*

As is well-known, the Frobenius theorem gives a criterion for D to be completely integrable:

Theorem 2 (Frobenius)**.** *A distribution D on M is completely integrable if and only if D is involutive, that is, D satisfies the condition: "For any open set $U \subset M$, the Lie bracket $[X, Y]$ of sections X, Y of D on U is also a section of D." Moreover, if D is completely integrable then the manifold M is a disjoint union $\bigcup_\lambda L_\lambda$ of the maximal connected r-dimensional integral manifolds L_λ of D, each L_λ being called a leaf of D.*

The problem of finding integral manifolds of distributions which are not completely integrable are treated by Cartan-Kähler theory.

Now let us proceed to consider integral curves of D. In order to well analyze the length functional we had better expand the class of curves to consider to that of the absolutely continuous curves: A continuous curve $\gamma : I \to M$, I being an interval $[a, b]$ of $\boldsymbol{R}$, is absolutely continuous if it has a derivative for almost all t, and if in any coordinate system the components of this derivative are measurable functions. We then define an integrable curve of D to be an absolutely continuous curve $\gamma : I \to M$ such that $\dot{\gamma} \in D_{\gamma(t)}$ for almost all $t \in I$. An integral curve of D is also called an integral path, a D-arc, or a horizontal curve.

If $\{X_1, \ldots, X_r\}$ is a local basis of D defined on an open set $U \subset M$, then a curve $\gamma : I \to U$ is an integral curve of D if

$$(*)\ \ \dot{\gamma}(t) = c_1(t)(X_1)_{\gamma(t)} + \cdots + c_r(t)(X_r)_{\gamma(t)}$$

for some functions $c_1(t), \ldots, c_r(t)$ for almost all t ∈ I. Conversely if the function $c_1(t), \ldots, c_r(t)$ and $\gamma(t_0)$ at some $t_0 \in I$ are assigned then the curve $\gamma(t)$ is determined by the ordinary differential equation $(*)$. In control theory $c_1, \ldots, c_r$ are interpreted as control parameters and D (or $X_1, \ldots, X_r$) is regarded as a control system.

If two points $p, q \in M$ can be joined by an integral curve of D, we say that q is reachable from p, If D is completely integrable then the set of all points reachable from p is the leaf passing through p.

Let us now introduce a class of distributions which are in a sense at the opposite end from the completely integrable distributions.

Definition 3. *A distribution D on M is called nonholonomic or bracket-generating if for any local basis $X_1, \ldots, X_r$ of D on U the collection of all vector fields $\{X_i, [X_i, X_j], [X_i, [X_j, X_k]], \ldots\}$ generated by Lie brackets of the X_i spans the whole tangent bundle TU.*

This definition can be rephrased as follows: Let $\underline{D}$ denote the sheaf of germs of section of D. Define the sheaves $\{\mathcal{D}^k\}_{k\geq 1}$ inductively by setting first $\mathcal{D}^1 = \underline{D}$ and then

$$\mathcal{D}^{k+1} = \mathcal{D}^k + [\mathcal{D}^1, \mathcal{D}^k] \quad (k \geq 1).$$

Then D is completely integrable if $\mathcal{D}^1 = \mathcal{D}^2$, and nonholonomic if $\bigcup \mathcal{D}^k = \underline{TM}$. This is called a "weakly derived system".

At a point $p \in M$, the flag of subsheaves gives a flag of subspaces of T_pM (the stalks of the sheaves):

$$\mathcal{D}_p \subset \mathcal{D}_p^2 \subset \cdots \subset \mathcal{D}_p^r = T_pM.$$

Definition 4. *Set $n_i(p)N = \mathcal{D}^i{}_q$. The integer list $(n_1(p), n_2(p), \ldots, n_r(p))$ of dimensions is called the growth vector of $\mathcal{D}$ at a point $p \in M$. The smallest integer $r = r(p)$ such that $\mathcal{D}^r{}_p = T_pM$ is called the step or degree of nonholonomy of distribution at p.*

The following theorem of Chow [2] is fundamental.

Theorem 5 (Chow)**.** *Let M be a connected manifold and D a nonholonomic distribution on M, then there exists for any two points $p, q \in M$ a piecewise smooth integral curve by which p and q can be joined.*

A detailed proof can be also found in [10], or in [9].

3 Example of distributions

3.1 Heisenberg algebra

We now discuss the simplest example of a contact distribution, whichi is called a "Heisenberg algebra". Let ω be the 1-form in $\mathbb{R}^3(x, y, z)$ given by $\omega = dz - (xdy - ydx)$. For example $f_1 = \frac{\partial}{\partial x} - y\frac{\partial}{\partial z}$ and $f_2 = \frac{\partial}{\partial y} + x\frac{\partial}{\partial z}$ forms s basis of sections of distribution D which is defined by $\omega = 0$. The Lie bracket $[f_1, f_2]$ is equal to $2\frac{\partial}{\partial z}$, so f_1, f_2 and $[f_1, f_2]$ are linearly independent at each point. We choose metric g such that f_1 and f_2 form an orthonormal basis of D. Then triple $(\mathbb{R}^3, D, g)$ is a (3 - dimensional) subriemannian contact manifold or (D, g) is a subriemannian contact structure. In general, contact forms are given by the formula

$$\theta = dz - \Sigma y_i dx_i,$$

where the coordinates z, x_i, y_i $(i = 1, \ldots, n)$ are in a $2n+1$ dimensional manifold. So contact distributions must have even rank $2n$.

3.2 Engel distributions

Definition 6. *A distribution of type $(2, 4)$ is said to be Engel if its maximal growth vector is $(2, 3, 4)$. A manifold endowed with an Engel distribution (M,D,g) is called an Engel manifold, where type $(2, 4)$ means that a rank of D is 2, and dimension of M is 4.*

In a neighborhood of any point of an Engel manifold we can find a local sections (or a local frame) X_1,X_2 such that X_1,X_2,$[X_1, X_2]$,$[X_1, [X_1, X_2]]$ spans the whole tangent bundle TM. Using coordinates x, y, z, w of M the distribution D is defined by

$$dz - ydz = dy - wdx = 0.$$

The expression for the distrtibution is called the Engel normal forms. D is also called a higher 2-order contact. We can construct an Engel manifold by prolonging a contact manifold of dimension of three.

3.3 Multinet distributions

The Martinet distribution on $\mathbb{R}^3(x, y, z)$ is spanned by the vector fields $\frac{\partial}{\partial y}$ and $\frac{\partial}{\partial x} + \frac{1}{2}y^2\frac{\partial}{\partial z}$ annihilated by the one-form $dz - \frac{1}{2}y^2dx$. We can see its growth vector is $(2, 3)$ everywhere except along the plane $y = 0$, where it is to be $(2, 2, 3)$. So D is contact everywhere except along $y = 0$.

3.4 Cartan distributions

As was shown by Cartan [1], a generic Pfaff system defined by three Pfaff equations in the space of five variables, that is, a tangent distribution D of rank 2 on $\mathbb{R}^5$ enjoys interesting properties: Its automorphism group makes a Lie group of dimension not greater than 14, and if the maximal dimension is attained, then the automorphism group is locally isomorphic to the exceptional simple Lie group G_2 and the tangent distribution D is locally isomorphic to the standard Cartan distribution defined as follows: Let $(x^1, x^2, x^3, x^4, x^5)$ be the standard coordinates of $\mathbb{R}^5$ and let the vector fields $X_1, \ldots, X_5$ be given by:

$$X_1 = \frac{\partial}{\partial x^1} - \frac{1}{2}x^2\frac{\partial}{\partial x^3} - (x^3 - \frac{1}{2}x^1x^2)\frac{\partial}{\partial x^4}$$

$$X_2 = \frac{\partial}{\partial x^2} + \frac{1}{2}x^1\frac{\partial}{\partial x^3} - (x^3 + \frac{1}{2}x^1x^2)\frac{\partial}{\partial x^5}$$

$$X_3 = \frac{\partial}{\partial x^3},\ X_4 = \frac{\partial}{\partial x^4},\ X_5 = \frac{\partial}{\partial x^5}.$$

These vector fields satisfy the following bracket relations:

$$\begin{cases} [X_1, X_2] = X_3 \\ [X_1, X_3] = X_4 \\ [X_2, X_3] = X_5 \\ \text{The others are trivial} \end{cases}$$

Let us take D to be the tangent distribution spanned by X_1 and X_2, that is,

$$\Gamma(D) = \langle X_1, X_2 \rangle\}.$$

Then, choosing a subriemannian metric g on D so that $\{X_1(p), X_2(p)\}$ forms an orthonormal basis of D_p, we consider the subriemannian manifold $(\mathbb{R}^5, D, g)$.

4 Hamiltonian formalism

If M is a manifold and $k \in \{0, 1, \cdots, \} \cup \{\infty\}$, we use $C^k(M)$ to denote the set of all real-valued functions on M that are class C^k, and $V^k(M)$ to denote the set of all vector fields of class C^k on M.

If N is a symplectic manifold with symplectic 2-form Ω, and $H \in C^1(N)$, we use $\overrightarrow{H}$ to denote *the Hamiltonian vector field* associated to H. $\overrightarrow{H}$ is the vector field V on N such that $\Omega(X, V) = \langle dH, X \rangle$ for every vector field X on N. If $H \in C^k(N)$ and $k \geq 1$, then vector field $\overrightarrow{H}$ is of class C^{k-1}. If $H, K \in C^1(N)$, then *the Poisson bracket* $\{H, K\}$ is the directional derivative of K in the direction of $\overrightarrow{H}$, i.e.,

$$\{H, K\} = \langle dK, \overrightarrow{H} \rangle = \Omega(\overrightarrow{H}, \overrightarrow{K}).$$

Then we have the following formulas

$$\{H, KL\} = \{H, K\}L + \{H, L\}K,$$

$$\{H, \{K, L\}\} + \{K, \{L, H\}\} + \{L, \{H, K\}\} = 0,$$

and

$$\overrightarrow{HK} = \overrightarrow{H}K + K\overrightarrow{H}.$$

Note also the fact that the map $H \to \overrightarrow{H}$ is a Lie algebra homomorphism from $(C^\infty(N), \{,\})$ to $(V^\infty(N), [,])$.

The cotangent bundle T^*M of a manifold M has a natural symplectic structure determined by the 2-form $\Omega_M = d\omega_M$, where ω_M is the Liouville form given by

$$\omega_M(x, \lambda)(v) = \langle \lambda, d\pi_M^*(v) \rangle \quad \text{for } v \in T_{(x,\lambda)}(T^*M),$$

π_M^* being the projection $T^*M \to M$. Relative to a coordinate chart

$$T^*\kappa = (x^1, \ldots, x^n, \lambda_1, \ldots, \lambda_n)$$

induced by a chart $\kappa = (x^1, \ldots, x^n)$ on M, we have the formulas

$$\omega_M = \sum_j \lambda_j dx^j,$$

$$\Omega_M = \sum_j d\lambda_j \wedge dx_j,$$

$$\overrightarrow{H} = \sum_j \left(\frac{\partial H}{\partial \lambda_j}\frac{\partial}{\partial x_j} - \frac{\partial H}{\partial x_j}\frac{\partial}{\partial \lambda_j} \right),$$

$$\{H, K\} = \sum_j \left(\frac{\partial H}{\partial \lambda_j}\frac{\partial K}{\partial x_j} - \frac{\partial H}{\partial x_j}\frac{\partial K}{\partial \lambda_j} \right).$$

To each vector field X on M we associated the function $H_X : T^*M \to \boldsymbol{R}$ given by

$$H_X(q, \lambda) = \langle \lambda, X(q) \rangle \quad \text{for } \lambda \in T_q^*M.$$

Then H_X is of class C^k if and only if X is. Moreover,

$$d\pi_M^*(\overrightarrow{H}_X(x, \lambda)) = X(x) \quad \text{for all } (x, \lambda) \in T^*M$$

The identity

$$\{H_X, H_Y\} = H_{[X,Y]}$$

holds for $X, Y \in V^1(M)$, and therefore the map $X \to H_X$ is a Lie algebra homomorphism from $(V^\infty(M), [,])$ to $(C^\infty(T^*M), \{,\})$.

If $X \in V^1(M)$ then the vector field $\overrightarrow{H}_X$ is called the *Hamiltonian lift* of X.

5 Normal extremals

Let (M, D, g) be a subriemannian manifold. If $(p, \lambda) \in T^*M$, then the restriction $\lambda|_{D_p}$ of λ to the subspace D_p of T_pM has well-defined norm, since D_p is an inner product space. We will use $\|\lambda\|_g$ to denote this norm. The function $E : T^*M \to \boldsymbol{R}$ given by

$$E(x, \lambda) = -\frac{1}{2}\|\lambda\|_g^2$$

is the energy function of the subriemannian structure (D, g).

Definition 7. *A normal biextremal of a subriemannian structure (D, g) is a curve $\Gamma : I \to T^*M$ such that*

(i) *Γ is an integral curve of the Hamiltonian vector field $\overrightarrow{E}$, namely*

$$\dot{\Gamma}(t) = \overrightarrow{E}_{\Gamma(t)}$$

(ii) *E does not vanish along Γ.*

A normal extremal is a curve in M which is a projection of a normal biextremal.

Theorem 8. *Let (M, D, g) be a subriemannian manifold. Then every normal extremal is locally length minimizing.*

This theorem is non-trivial, but the proof is similar to that of riemannian case. However, contrary to the riemannian case, the converse of the theorem does not hold. There appeared several papers asserting that every minimizer of a subriemannian manifold is a normal extremal. But Kupka [5] and Montgomery [8] proved that there exists a subriemannian manifold and a minimizer of the subriemannian manifold which is not a normal extremal. Such a minimizer is called an abnormal minimizer. In the following sections we will give a characterization of the abnormal minimizers.

6 Characteristic system

Let (N, Ω) be a symplectic manifold. For a submanifold S of N we define the characteristic system (bundle) $\mathrm{Ch}(S)$ of by

$$\mathrm{Ch}(S) = TS \cap (TS)^\perp,$$

that is, the fibre $\mathrm{Ch}(S)_s$ on $s \in S$ is given by

$$\mathrm{Ch}(S)_s = T_sS \cap (T_sS)^\perp,$$

where

$$(T_sS)^\perp = \{v \in T_sN; \Omega(v, u) = 0 \text{ for all } u \in T_sS\}.$$

Let $F_1, \ldots, F_r$ be local defining equations of S, say, defined on a neighbourhood U of $s_0 \in S$ such that $(dF_1)_s, \ldots, (dF_r)_s$ are linearly independent for $s \in U$ and

$$U \cap S = \{F_1 = \cdots = F_r = 0\}.$$

From the very definition of Hamiltonian vector field we see immediately that

$$\{(\overrightarrow{F_1})_s, \ldots, (\overrightarrow{F_r})_s\}$$

forms a basis of $(T_sS)^\perp$ for $s \in U$. Hence we have

$$\mathrm{Ch}(S)_s = T_sS \cap \langle (\overrightarrow{F_1})_s, \ldots, (\overrightarrow{F_r})_s \rangle.$$

Let $\Omega_S = \iota_S^*\Omega$, where $\iota_S : S \to N$ is the canonical inclusion, and let:

$$\mathrm{Null}_s(\Omega_S) = \{v \in T_sS; \Omega_S(v, u) = 0 \text{ for all } u \in T_sS\}.$$

Then it is clear that

$$\mathrm{Ch}(S)_s = \mathrm{Null}_s(\Omega_S).$$

We then have:

Proposition 9. *For a submanifold S of a symplectic manifold (N, Ω), the characteristic system* $\mathrm{Ch}(S) = \bigcap_{s\in S} \mathrm{Ch}(S)_s \subset TS$ *is given by:*

$$\begin{aligned}\mathrm{Ch}(S)_s &= T_sS \cap (T_sS)^{\perp} \\ &= (T_sS) \cap \langle (\overrightarrow{F_1})_s, \ldots, (\overrightarrow{F_r})_s \rangle \\ &= \mathrm{Null}_s(\Omega_S)\end{aligned}$$

If $\dim \mathrm{Ch}(S)_s$ *is constant, then* $\mathrm{Ch}(S)$ *is a completely integrable subbundle of TS.*

The last assertion of the proposition follows from the exactness of the symplectic form.

7 Abnormal extremals

Let (M, D, g) be a subriemannian manifold. Recall that we denote by $D^{\perp}$ the annihilator bundle of D and by $\mathrm{Ch}(D^{\perp})$ its characteristic system.

Definition 10. *An abnormal biextremal of (M, D, g) is an curve $\Gamma : I \to D^{\perp}\backslash\{O\}$ (O denoting the zero section) such that $\dot{\Gamma}(t) \in \mathrm{Ch}(D^{\perp})_{\Gamma(t)}$ for almost all $t \in I$. An abnormal extremal of (M, D, g) is a curve in M which is a projection of an abnormal biextremal.*

By using the Pontryagin Maximam Principle on Control system, it is shown that the following theorem holds (see [6], p.81, Appendix B).

Theorem 11. *Let (M, D, g) be a subriemannian manifold, and let $\gamma : [a, b] \to M$ be a length-minimizer parametrized by arc-length. Then γ is a normal extremal or an abnormal extremal.*

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（教育研究報告）

浸水住宅復旧用，泥土バキューマーの開発

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近年，地球温暖化の影響でわが国でも大雨やゲリラ豪雨，台風などにより風水害が増加傾向にある[1]．それらにより多発する住宅の浸水被害の復旧は災害ボランティア等の人力に頼ることになる．令和2年7月6日からの大雨による大分川の氾濫に伴う水害[2]の際には，機械工学科材料力学究室学生5名とともに由布市狭間町の瓦工場の復旧作業を手伝った．床面には水を含んだ非常に細かい粒子の泥が，厚さ15cm程堆積していた．緩い羊羹のような感じのこの泥を．我々はスコップで一輪車に積み込み20m程離れた河原に捨てる作業を延々と繰り返した（図１）．学生たちはこの時，人力による泥土処理の大変さを痛感した．そこで，5年前期の必修科目エンジニアリングデザインのテーマとして浸水した家屋の汚水・泥土を楽に排出処理するための装置の開発を掲げ取り組んだが，前期だけの時間内では完成に至らず，結局，佐藤初秀君（現　矢崎総業）が卒業研究のテーマとして引継ぎ制作を行った．佐藤君の努力で汚水を連続的に吸い出す装置は完成したが，泥土を効率よく処理するところまでには至らなかった．次の年，石崎雄大君が泥土専用のスコップ式吸引ヘッドを製作し一応の完成をみた．本報告では，泥土バキユーマの制作過程と性能につて記述し，より多くの場面での活躍を期待するものである．

キーワード：床下浸水，水害，汚水，汚泥，泥土処置，吸引機，連続排水

１．水害復旧の現状

令和5年に行われた水害サミット[3]によれば，泥処理に関して清掃の場面に応じた作業用機械を使用することを提言している．体育館、学校の教室等の清掃には，消防ポンプの使用が有効で，清掃が短時間で済み，後の復旧も安価であるとしている．道路施設、下水道施設、住宅などに流入した土砂の撤去には、下水道管路清掃車が有効である．流出土砂はヘドロ状なので，強力吸引車を導入すれば作業効率が上がるとも記されている．大規模な災害の際，一般家庭の水害復旧に強力吸引車が導入できる可能性は低く，掃除機並みの手軽な泥土吸引装置が強く求められると思われる．

図１　学生による水害復旧ボランティア

２．制作装置の目標スペック

制作する装置は以下のような性能を持つこととした．

(1) 泥土を含んだ水を毎分50L以上吸引し，10m先に運搬排出が出来る．
(2) 直径10㎜以下の小石が混ざる泥土も処理することが出来る．
(3) ある程度乾いた泥も水と混合して 吸引処理できる．
(4) 一般の掃除機で吸い取ったのと同じ程度に仕上がる．
(5) 人の手で持ち運べ る重さ・大きさ(15kg 以内)
(6) トラブルなく長い時間連続的に吸引・排出が出来る．
(7) 電源や水道のない所でも作業が可能

２．装置の原理

図２に制作する装置の構造図を示す．すでに乾湿両用の掃除機が市販されているが，業務用でも内容量が少なく，短時間しか吸引することは出来ないので，掃除機とは別に吸引物を貯蔵する中間タンクを設け，その中に排

図２　装置の構造図

水用の水中ポンプを設置して吸引をしながら排出ができる構造となっている．掃除機には空気だけが流入するので，長時間の運転が可能となる．泥土は吸引しにくいので，給水用のポンプを使って吸引ヘッドの部分に水を供給し，水と泥土を混合した状態にして吸い上げる．電源がダウンしている場合に備え，1.8ｋWの小型発電機も用意した．

３．各部の製作と結果

3．1　汚泥水吸引機　汚泥水吸引装置には乾湿両用掃除機であるニルフィクスの AERO 21-01 PC を用いた．泥土水が掃除機に流れ込まないように，中間タンクからの配管はタンク上方から垂直に引き出し，タンクふたの部分には泥土水遮断板を取り付けた．また，万一泥土水が掃除機に流れ込んだ場合でもフ ィルターに泥水が当たらないように，空気流入側にフィルターカバ ーを付けた．さらに掃除機のタンク部分に監視窓をつけ泥土水の侵入が検知できるようにした（図３）．掃除機の仕様を表１に示す．ここで揚程と吸い込み量はカタログ値ではなく実際に水を吸って計測した値である．

3．2　中間貯蔵タンク　中間貯蔵タンクはコダマ樹脂工業株式会社の POM-60 を用いた．しっかり蓋を閉めるための金具がついており，水中ポンプが十分に入る大きさであるが，樹脂製で軽いのでこれを選定した．このタンクに掃除機を接続して中の空気を抜いたところ，タンクが負圧に耐えきれず，つぶれてしまうトラブルが起こったので，図４に示すように内側に補強リブを取り付けた．泥土水吸引口と排水口はタンクの曲率に合わせたスペーサを3Dプリンタで製作し，フランジを取り付けた．排水ホースの連結部は町田式のカップリングにしてワンタッチで着脱できるようにした．

3．3　タンク内汚泥水排出装置　中間貯蔵タンク内の汚泥水を排出する水中ポンプは，吸引掃除機を上回る揚程および排出量が要求され，直径10㎜程度の小石も吸い上

表１　掃除機およびポンプの仕様

	AREO 21-01 PC	OM3	FP-10S
Power supply	Single 100V 60Hz	Single 100V 60Hz	Single 100V 60Hz
Lift (m)	3.5	4	7
Discharge amount (L/min)	72	100	80
Weight (kg)	7.5	5.9	3.4
Bore (mm)	30.5	32	15/25
Power consumption (W)	1200	320	160

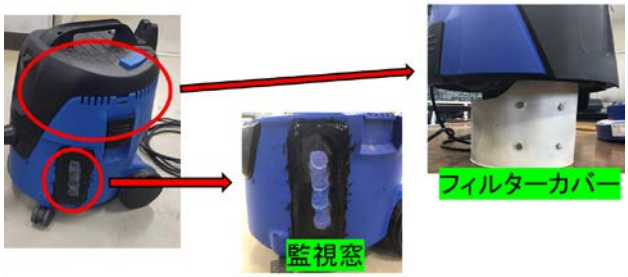

図３　掃除機の改良

図４　つぶれた中間貯蔵タンクと補強リブ

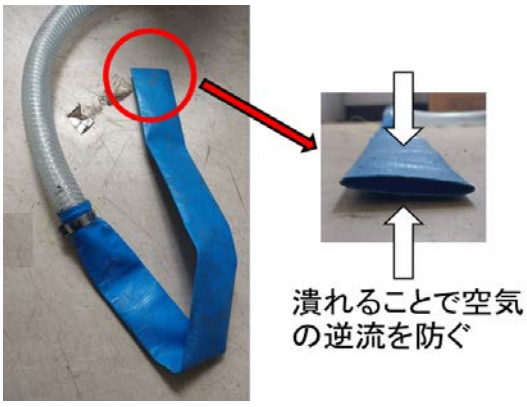

図５　排出ホースの先端

げる性能が必要となる．排出用ポンプ にはツルミポンプの OM3 を用いた．排出ポンプの仕様を表 1 に示す．中間貯蔵タンク内に汚水が無いとき水中ポンプは揚程が無くなるので排水ホース側から空気が流入してヘットからの吸引が出来なくなる．これを防止するために，排水ホースの先端にはフレキシブルな部分を設け，負圧でつぶれることで空気の逆流を防止するようにした（図５）．

3．4　吸引ヘッド　泥土を効率よく処理するためには水と混合して泥土水にして吸引することが大切である．そこで吸引ヘッドには水を供給するホースを取り付けた．水の供給は水道を利用するが，水道が被害を受けている場合を想定して水中ポンプ（ツルミポンプFP-10S）を準備した．ポンプの仕様を表1に示す．大野川の河口から採取した泥を用いて吸引の実験を行い，最適なヘッド形状を模索した．最初の段階では３Dプリンタで自作した掃除機型ヘッドを使用して吸引実験を行ったが，ホースに汚泥が詰まってうまく吸引できない結果となった．供給水量が少ないことと，吸い込みホース径が小さい(内径32㎜)ことでとこのような現象が起こる．そこで吸引ホース内径を38㎜にして市販の回転ブラシ付き掃除機ヘッドに給水パイプを取り付けての実験を行た（図6）．回転ブラシは本来空気圧で回転するが，今回それは望めないので，ゴム製のタイヤを取り付け，ヘッドを前後に動かすことでブラシを回転させる構造にした．しかし，ブラシを取り去ったほうが効率よく泥土水を吸引することが分かった．そこで，図７に示すような，ブラシのない市販の大型吸引ヘッドに，φ15㎜からφ25㎜に大径化した給水ホースを取り付けて実験を行った．その結果，泥を水に混ぜて吸い出し，中間貯蔵タンク内の水中ポンプで遠方に排出することに成功した．40L程の泥を水と混ぜて輸送するのに約1分程度の時間がかかった．基本的に掃除機であるので水たまりを残さずに仕上げることが出来る．しかし，床面に堆積した硬めの泥の場合，水と混合するのに時間がかかる．このような場合のアイテムとしてスコップ型のヘッドを製作した．泥をすくい上げ，皿の上で水と混合して管に吸い込む仕組みである．このヘッドの性能はウォータージェットカッターの水槽底に堆積したガーネット粉を除去することで試した．最終仕上げは掃除機ヘッドが必要であるが，そこに堆積した重いガーネット粉も，ある程度の大きさのプラスチック切断くずも含めて吸い上げ除去することができた．

４．災害への適応例

2021年8月11日から18日にかけて筑後川支流で内水氾濫が発生し，20日時点で、床上浸水518棟，床下浸水2194棟，道路被害254カ所が記録された[4]．久留米市内に住まいを構える著者の友人宅も床下浸水に見舞われたと聞き，8月

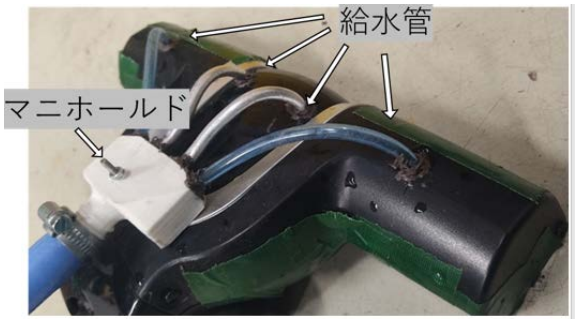

図６(a)　ブラシ付きヘッドと給水管

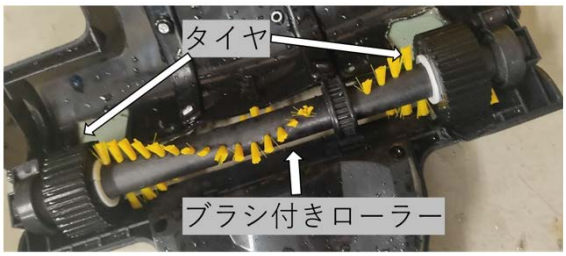

図６(b)　ブラシと駆動タイヤ


図７　吸引ヘッド　最終形状

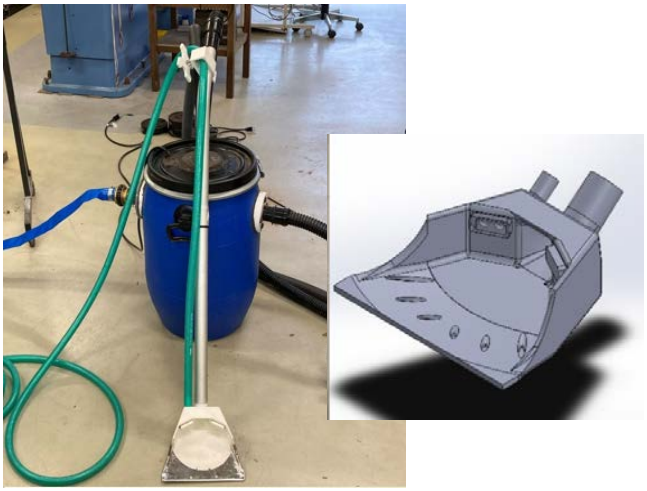
図８　スコップ型吸引ヘッドと中間貯蔵タンク

図９　床下浸水への対応

16日に装置を車に積んで救援に出かけた，新築の家屋床下に5㎝程水が溜まっていたが，幸い泥は混入していなかったので．ヘッドに給水する必要が無いと判断し，通常の掃除機ヘッドを使うことにした．吸引掃除機や中間貯蔵タンクを床下に入れることができないので，吸引ヘッドと中間貯蔵タンクを繋ぐホースを13ｍ程延長し，作業者が吸引ヘッドを持ち，一か所から床下に入り移動しながら水を吸い込む作業を行った．2時間ほどの作業の結果ほぼすべての水を排出することが出来た．

2022年9月20　台風14号通過の影響で大分高専専攻科棟エントランスホールおよび５M教室に大きな水たまりが発生していた．水たまりは一番深い場所で水深3㎝程で，面積では教室床面の半分ほどに及んでいた．これも通常の掃除機ヘッドで対応した[5]．

2023年10月27日大分高専機械工場で水道配管が破損したのに気づくのが遅くなり，配線ピットに水が満ちてあふれる状態にまでなっていた．危険なので電源を落とした後の排水作業となった．配線ピットは幅が20㎝程しかないので．ヘッドを外しパイプのままで吸引を行った．

５．まとめ

洪水による家屋の浸水災害の普及はほとんどが手作業となり，多くの時間と人手を要する．このような災害は今後増加する傾向にあり，効率の良い作業が望まれる．本報告で示した泥土バキューマは少なくとも床面に堆積した水を連続的にきれいに吸い取り遠方に排出するのに有効である．実戦経験はないが，泥や細かい砂も水と混合して吸引排出が出来ることも確認している．構造は簡単なので同じような装置を大量に作れば大規模災害の復旧に役立つと思われる．今後は実戦での経験を積み，さらに使いやすく改良を続けることが必要であり，お役に立てる機会があれば出かけていきたいと考えている．

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https://youtu.be/NIe850sChuA

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